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# Interspecific Hybridization among Insects with a Report on Crossbreeding Experiments with Stink Bugs[1]

R. I. SAILER, *Entomology Research Branch, Agr. Res. Serv., U.S.D.A.*

NOTE: This paper and the three which follow it were presented as a symposium entitled "Genetics in Entomology; Hybridization and Pesticide Resistance" (Dr. H. H. Schwardt, Cornell University, Moderator) at the Eastern Branch Meeting of the Entomological Society of America held in Philadelphia, Pennsylvania, November 16–17, 1953. A paper by Dr. Floyd F. Smith, also presented on this program, was not available in time to be included here.—EDITOR

Hybridization is a subject in which I have been interested for several years. However, being a taxonomist, I have had little time in which to conduct crossing experiments. Data from such work as I have done have piled up in a largely undigested form, and my comments here must be preliminary in nature.

Almost 10 years ago I undertook a revision of the genus *Chlorochroa*,[2] which includes the economically important Say's stink bug (*C. sayi* Stål) and the conchuela (*C. ligata* (Say)). Almost immediately I discovered that in the intermountain region of the Northwest at least three of the species, including the conchuela, break down into a maze of intermediate populations. One of the species is found over most of eastern United States, the conchuela is southwestern but extends north to Canada, and the third species is restricted to Oregon, Washington, and British Columbia. All three occur together in British Columbia, and the first two are found together east of mountains in the northern high plains region. Over much of Montana, Idaho, Utah, and eastern Washington and Oregon populations occur which cannot be assigned to any one of these species and which exhibit characters that clearly suggest hybrid origin involving two or even all three species. This brought my study to a halt, for I couldn't decide whether to deal with the forms as species, subspecies, local populations, or hybrids.

The possibility that hybrids were involved was suggested by the work of Foot & Strobell (1914), who succeeded in obtaining fertile hybrids between *Euschistus variolarius* (P. de B.) and *servus* (Say), two of the most common stink bugs found in eastern United States. Furthermore, their hybrids presented the same intermediate appearance as did the natural populations of *Chlorochroa* in the Northwest.

I therefore decided to discontinue work on the *Chlorochroa* revision and test the possibility that questionable populations such as those encountered in this genus could be considered of hybrid origin. In this course of action I was influenced by the opinion widely held in taxonomic circles, as late as 8 or 10 years ago, that it was little short of heresy to speak of fertile hybrids between species of animals. There is already considerable literature dealing with interspecific hybrids. Among the earliest well-authenticated records are those concerning butterflies and moths. However, such records were seldom more than notices that a different-looking specimen had been obtained. Few attempts were made to determine whether the hybrids were fertile. Occasionally it was noted that similar specimens had been captured in the field.

About 1920 the first instance of interspecific hybridization was obtained in the genus *Drosophila*. Geneticists were quick

[1] Supported in part by a grant from the Penrose Fund of the American Philosophical Society.

[2] *Chlorochroa* Stål is a homonym, but until certain generic relationships are clarified it seems best to continue using this name rather than to accept a replacement name which might soon be displaced because of generic synonymy.

to utilize hybridization as a tool in their work, and since 1930 much effort has been directed toward such studies in *Drosophila*. Most of these studies have been made by or under the direction of T. Dobzhansky at Columbia University and J. J. Patterson at the University of Texas. This work was brought together and published by Patterson & Stone (1952). Since 1945 many instances of laboratory hybridization between species of mosquitoes and species of Lepidoptera have been reported. In fact, the evidence has now piled up to a point where only the most obstinate or the uninformed continue to hold the view that hybrid sterility is a necessary species criterion.

This raises the question of a species definition, and in my subsequent discussion I use the one originated by geneticists and generally accepted by taxonomists—namely, an actually or potentially interbreeding natural population that is reproductively isolated from other such populations. Since we cannot hope to apply crossbreeding tests to more than a small number of the innumerable forms of life, we all find it necessary to rely on the ability and knowledge of the taxonomist who decides that a form is a species. The taxonomist ordinarily uses structure as the basis for his decision. If a form is distinguished by certain structural characteristics that are not found to intergrade with those of related forms, it is assumed that the population is reproductively isolated and thus qualifies as a species under the geneticist's definition.

All this emphasizes the disjunct nature of species. Yet every taxonomist has repeatedly encountered instances in which his decision to place a form as a species or subspecies was admittedly arbitrary. Judging from the work on *Drosophila*, the geneticist is better off only to the extent that he is able to apply a more discriminating technique to the study of questionable forms. Yet it is clear that often the most careful study of certain forms of *Drosophila* has not allowed definite assignment of species or subspecies status. We are left with the obvious conclusion that life forms grade from freely interbreeding populations, through populations that are reproductively isolated in practice but still potentially capable of crossing and producing some fertile offspring, to those that are incapable of interbreeding in any degree.

My purpose here is to consider the possible effect of hybridization on the course of evolution. Hybridization is known to occur at all levels from the intraspecific strain to interspecies, and in some groups even between genera. In the lower levels it is a recognized cause of gene flow and results in the movement of characters through interbreeding populations. The situation is different at the interspecies level, where zoologists generally believe that hybridization has little effect on the course of evolution, and it is with this view that I wish to take issue.

A little over a decade ago Dobzhansky was able to cite only five cases of hybridization in the genus *Drosophila*. Subsequent studies enabled Patterson and Stone to list at least 86 interspecific crosses in the same genus. About 70 of these crosses produced fertile offspring of one or both sexes, and the authors admitted that gene exchange between the crossed species was possible.

At present there are 613 known species of *Drosophila*. They are placed in 9 subgenera, 2 of which are subdivided into species groups—*Lophophora* with 7 and typical *Drosophila* with 22. No crosses between species belonging to different subgenera or different species groups have been obtained. Within species groups the possibilities for obtaining additional crosses are far from exhausted, for only a few of the species have been tested in what approaches all possible combinations. It is also apparent that many of the crosses were successful only after repeated trials.

Not being a geneticist, I should doubtless exercise caution in any expression of views that departs significantly from conclusions based on such a mass of data as those presented by Patterson & Stone (1952). Nevertheless, I do question their statement which reads as follows (page 501):

> "In fact the definition of a species as an evolving unit must be based on the concept that the gene systems available to a species as they exist or occur by mutation or recombination are responsible for its further existence and evolution. This does not preclude some hybridization and gene exchange which may benefit a species, but such donations of genes from another form cannot dominate its evolutionary progress."

My reason for questioning this assertion is based largely on their discussion of evolution in the *virilis* group, where they admit the probability that the species *americana* was the result of the natural crossing of *texana* and *novamexicana* (pages 448 and 449):

"The inversions present in *americana* show that this form is a mixture of gene sequences from *texana* and *novamexicana*. It is in this sense a hybrid form, whether or not *texana* and *novamexicana* were species or subspecies at the time their heterozygotes produced the basic configurations of *americana*."

The potential importance of hybridization is again indicated by the evidence cited by Patterson and Stone that in at least three *Drosophila* crosses the males are sterile when backcrossed to females of their parent species but are fertile when mated to hybrid females of the same cross. This strongly suggests the origin of one kind of reproductive isolation.

The insect physiologist Wigglesworth (1953) has recently reported that a German worker obtained hybrids between several hawk moths, and found that the $F_1$ males were fertile, but that the $F_1$ females died in the pupal stage. He prevented this mortality by withdrawing all the blood from the female pupae and replacing it with blood from hybrid male pupae. According to Wigglesworth, this is clearly the result of a sex-linked genetic disturbance involving a growth-hormone factor.

Clarke & Sheppard (1953) were able by a hand-pairing technique to overcome sexual isolation between four species of North American swallowtails and obtain hybrids that were partially fertile only in backcrosses. A steady increase in fertility was obtained with repeated backcrosses. They point out that the members of the "*Machaon* complex" to which these butterflies belong are closely related, and are in fact treated as subspecies by the British Museum. They conclude that these forms must be treated as extreme subspecies rather than valid species, since some of the backcrosses are fertile. In comparison with the studies in the *Drosophila* this is an extremely cautious view, especially since three of the species of swallowtails occur together in northeastern North America and two in the southwestern part of the continent. In fact, the range of one species is completely overlapped by one of the other three.

I have succeeded in obtaining hybrids from reciprocal crosses of the stink bugs *Euschistus servus* and *variolarius*. These two species are found over most of the United States. In most localities where they occur they are often collected in the same sweep of a net. The two species are readily distinguishable in both sexes. Whereas *variolarius* is structurally uniform throughout its range, *servus* breaks up into two subspecies, one being *euschistoides* (Voll.), which until recently has been treated as a distinct species. Typical *servus* is common in southeastern United

**Table 1.—Results[1] of breeding experiments with *Euschistus servus* (S) and *E. variolarius* (V) and hybrid strains of these species.**

| Species or Hybrid Strain | Total Females | Mating Days | Observed Matings | Matings per Mating Day | Total Eggs | Eggs per Female | Per Cent of Fertile Eggs |
|---|---|---|---|---|---|---|---|
| V | 201 | 4,720 | 314 | 0.067 | 8642 | 43.0 | 91.4 |
| S | 176 | 5,003 | 321 | .044 | 7515 | 42.7 | 90.5 |
| S♀ × V♂ | 409 | 15,409 | 43 | .003 | 8534 | 20.9 | .4 |
| V♀ × S♂ | 319 | 13,562 | 42 | .003 | 6868 | 21.5 | 1.7 |
| $F_1$ VS (first series) | 7 | 648 | 48 | .074 | 2669 | 381.3 | 91.0 |
| ($F_1$ VS)♀ × V♂ | 6 | 263 | 27 | .123 | 592 | 98.6 | 79.1 |
| ($F_1$ VS)♀ × S♂ | 5 | 234 | 22 | .093 | 592 | 118.4 | 78.9 |
| V♀ × ($F_1$ VS)♂ | 5 | 213 | 20 | .094 | 201 | 40.2 | 58.1 |
| S♀ × ($F_1$ VS)♂ | 7 | 292 | 8 | .027 | 253 | 36.1 | 64.9 |
| $F_2$ VS | — | — | — | — | 894 | — | 69.2 |
| $F_1$ VS (second series) | 5 | — | — | — | 1760 | 352.0 | 85.9 |
| $F_4$ VSS | 11 | 1,690 | 49 | .028 | 3219 | 292.6 | 56.1 |
| $F_1$ VSSS (incomplete) | 5 | 541 | 7 | .013 | 452 | 90.4 | 88.0 |
| ($F_1$ VSSS)♂ × S♂ (incomplete) | 6 | 540 | 9 | .017 | 412 | 68.7 | 88.1 |

[1] The first four lines combine the results of six tests conducted over a period of 2 years, the remaining ten lines are concerned with but one test for each of the hybrid strains.

States, but *euschistoides* extends from coast to coast across the northern part of the country. Through a long belt from Maryland to Kansas the two subspecies of *servus* intergrade, and it is from this belt that my laboratory colonies originated.

When Foot & Strobell (1914) crossed *variolarius* and *servus*, they carried their hybrids only to the $F_2$ generation, whereas I have carried populations to the $F_3$ generation. In addition I have carried a backcrossed line—$\frac{1}{4}$ *variolarius*+$\frac{3}{4}$ *servus*—to $F_5$ and then obtained backcrosses providing $\frac{1}{8}$ *variclarius*+$\frac{7}{8}$ *servus*, $\frac{1}{16}$ *variolarius* + $\frac{15}{16}$ *servus, and* $\frac{5}{8}$ *variolarius*+$\frac{3}{8}$ *servus*. In these studies records have been kept which permit comparison of sexual acceptance, egg production, and egg fertility. Reared adults of all lines were preserved in order to learn the effect of hybridization on the characters found useful in distinguishing *variolarius* and *servus*.

The data presented in table 1 indicate the existence of two barriers to successful crossing of *variolarius* and *servus*. First is the barrier of sexual compatibility. In my experiment males and females of the same species were placed together, and at the same time and from same stocks males of one species were placed with females of the other. All females were virgin, and all specimens were of approximately the same age. Twice each day the number of mating pairs was recorded, and any eggs found were removed, counted, and held for hatching. From the number of matings per pair per day it was calculated that the average number of days for one observed mating for each pair was 15 for *variolarius*, 23 for *servus*, and 333 for a female of one species placed with a male of the other. Expressed another way, males will mate with females of their own species 17 times more readily than with females of the other species in the absence of free choice.

The second barrier to crossing of the two species is egg fertility. As shown in table 1, the average fertility of *variolarius* eggs was 91.4 per cent and that of *servus* 90.5 per cent, but eggs laid by *variolarius* females segregated with *servus* males were only 1.7 per cent fertile, and those of *servus* females segregated with *variolarius* males were even less fertile, averaging only 0.4 per cent. Once a sufficient number of individuals were used, these two barriers were broken to the extent that a few $F_1$ hybrids were obtained. These hybrids exhibited very great vigor, for 18 $F_1$ females produced on an average 199 eggs apiece, or 4.6 times as many as females of either pure species. The eggs of seven $F_1$ females mated to $F_1$ males proved to be 91.0 per cent fertile. Those laid by $F_1$ females mated to either *variolarius* or *servus* males were about 79 per cent fertile. Eggs produced by *variolarius* females mated to $F_1$ males were only 58.1 per cent fertile, and those of *servus* females mated to $F_1$ males 64.9 per cent. There appears to be no sexual barrier between the $F_1$ hybrids and either pure species. In fact, individuals of either species seem to mate more frequently with $F_1$ hybrids than with individuals of their own species. However, the 0.027 mating per day for *servus* females with the $F_1$ hybrid males suggests that the high values for the other combinations involving $F_1$ hybrids are possibly due to an insufficient sample. The data obtained from a second series of $F_1$ hybrids, for which only the total number and fertility of eggs were recorded, confirmed the high productivity of $F_1$ hybrids. Eggs laid by $F_2$ hybrids were only 69.2 per cent and those laid by $F_4$ $\frac{1}{4}$ *variolarius*+$\frac{3}{4}$ *servus* were only 56.1 per cent fertile. $F_1$ backcrosses from the $F_5$ generation of this line mated to *servus* produced eggs that were 88 per cent fertile.

Having once produced fertile hybrids between *variolarius* and *servus*, it became possible to study the effect of hybridization on characters commonly used to separate the species. Several external characters, such as color, head shape, and the degree to which the humeral angles are spinose, permit easy recognition of the species. Unfortunately they vary from generation to generation, probably because of environmental factors, so that it is sometimes difficult to evaluate the effect of hybridization. To avoid this difficulty I have used an internal structure of the male genitalia to illustrate the effect of hybridization. This structure is called the penisfilum and consists of a watchspring-like extension of the gonoduct from the aedeagus. The difference between the structure found in *variolarius* and that in *servus* is one of length, as shown in the upper left corner of chart 1. Although its length varies considerably within each species, there is a clear gap between the two which is not

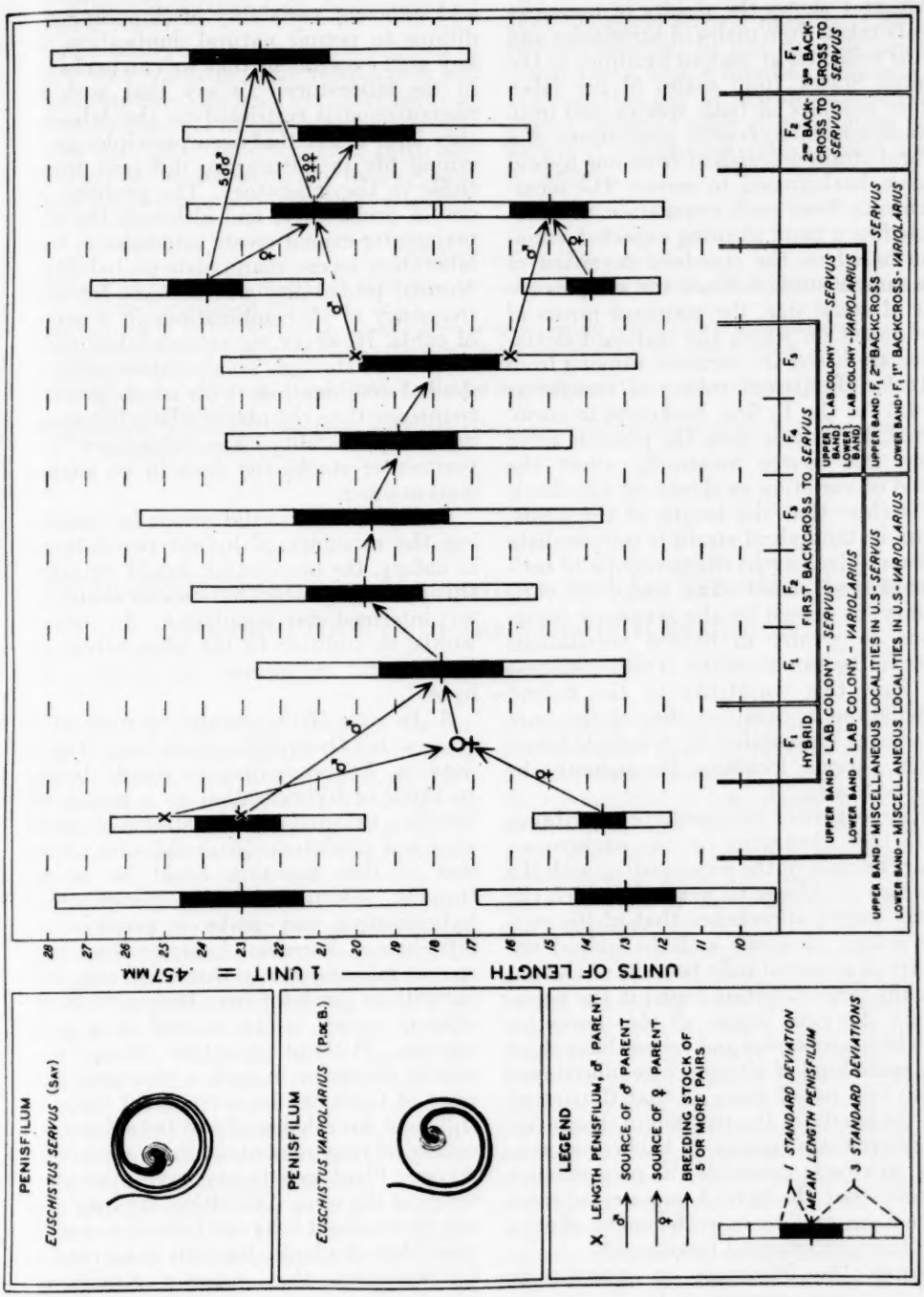
PENISFILUM
EUSCHISTUS SERVUS (SAY)
PENISFILUM
EUSCHISTUS VARIOLARIUS (P.DE B.)
LEGEND
X LENGTH PENISFILUM, ♂ PARENT
SOURCE OF ♂ PARENT
SOURCE OF ♀ PARENT
BREEDING STOCK OF 5 OR MORE PAIRS
1 STANDARD DEVIATION
MEAN LENGTH PENISFILUM
3 STANDARD DEVIATIONS
UNITS OF LENGTH
1 UNIT = .457MM
F1 HYBRID
F1
F2 FIRST BACKCROSS TO SERVUS
F3
F4
F5
UPPER BAND - LAB. COLONY - SERVUS
LOWER BAND - LAB. COLONY - VARIOLARIUS
UPPER BAND - MISCELLANEOUS LOCALITIES IN U.S - SERVUS
LOWER BAND - MISCELLANEOUS LOCALITIES IN U.S - VARIOLARIUS
UPPER BAND LAB. COLONY — SERVUS
LOWER BAND LAB. COLONY - VARIOLARIUS
UPPER BAND - F1 2ND BACKCROSS — SERVUS
LOWER BAND - F1 1ST BACKCROSS - VARIOLARIUS
F2 2ND BACK-CROSS TO SERVUS
F1 3RD BACK-CROSS TO SERVUS
5♂♂
3♀♀

CHART 1.—A comparison of an internal structure of the male genitalia as it was found to occur in *Euschistus servus*, *variolarius*, and several hybrid strains involving these species.

known to be bridged by any specimens collected in the field.

Chart 1 shows the results of measurements taken from males of *variolarius* and *servus* collected at various localities in the United States, from males of my laboratory colonies of both species, and from populations of successive generations of a hybrid strain descendent from one hybrid female backcrossed to *servus*. The measurements from each population are presented as a band showing expected variation based on the standard deviation of the sample studied. Since the samples are not of equal size, the standard errors of the means on which the standard deviations are based are variable, ranging from 0.12 for the parent colony of *variolarius* to 1.5 for the $F_1$ first backcross to *variolarius*. In no case does the possible error from this source materially affect the trend of variation as shown on the chart. It is clear that the length of the penisfilum in the hybrid strain is intermediate between the lengths characteristic of *variolarius* and *servus*. The range of variability, as shown by the standard deviations, is greater in hybrid populations than in the parent colony of either species. In fact, this variability in the hybrid populations approaches that of the pure species as represented by a sample taken from various localities throughout the United States.

The feature of intermediate inheritance is further illustrated by the backcrosses near the close of the series ending with the $F_1$ third backcross to *servus*, in which the mean length approaches that of the parent colony of *servus* and the hybrid ancestry is apparent only because of the unusually large variation found in the population. To some degree all the characters in which *variolarius* and *servus* differ show the same kind of intermediate inheritance in hybrid populations as that illustrated by the length of the penisfilum. However, in external appearance $F_1$ backcross progeny so closely resemble the predominant species that the hybrid ancestry of most specimens would escape the notice of even the most experienced taxonomist.

From the literature on interspecific hybridization, supported by the results of my crossbreeding experiments, I present the following generalizations:

1. Since fertile interspecific hybrid populations can be developed in the laboratory, we can infer that they may also occur in nature. Nature has time, space, and sufficient variability of climatic conditions to permit natural duplication of any such experiment that we can perform in the laboratory. To say that such a phenomenon is restricted to the laboratory is to assert that basic principles governing life in nature are different from those in the laboratory. The problem is one of probability, and although the experimenter cannot create principles in the laboratory he can manipulate probability. Normal probability will account for the frequency of all combinations in a game of cards. However, an accomplished card shark can, through manipulation, obtain desired combinations with much greater frequency than the player who relies upon normal probability. The laboratory experimenter stacks the deck in an analogous manner.

2. If there is no valid reason for doubting the existence of hybrid populations in nature, the taxonomist should consider this possibility when he tries to evaluate an intermediate population. In other words, in addition to the alternatives of species and subspecies, we should add hybrid.

3. In view of the number of successful crosses in *Drosophila*, Culicidae, Lepidoptera, Pentatomidae, we should begin to think of hybridization as a means of breeding new and superior strains of parasites and predators. No doubt some progress in this direction could be made through selection within species, but hybridization can make it possible to introduce a desirable character from one species into another so that an ill-adapted parasite or predator may become a more efficient agent in the control of a pest species. Without question there are serious obstacles to such a program, but most of them can be overcome if there is sufficient knowledge of the behavior and ecological requirements of the species concerned. Plant geneticists have overcome many of the same difficulties. We may admit that animal behavior is more complex than that of plants, but this is no reason for assuming that superior strains of beneficial insects cannot be produced through application of similar techniques. Man has been able to domesticate many animals and modify their structure and behavior to suit his need or fancy. In dogs

it is almost certain that several species were involved.

In recent years we have had a lesson in just how versatile and resourceful our insect enemies can be. They have met one after another of our powerful new insecticides and, after suffering what often appeared to be catastrophic losses, have returned to renew their threats to our comfort or economy. There is ample evidence that biological control must hold an important position in our struggle against insect pests, and a breeding program involving the use of hybridization techniques seems to offer great promise as a means of outmaneuvering at least some of them.

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# Hybridization among Mosquitoes and Its Possible Relation to the Problem of Insecticide Resistance

LLOYD E. ROZEBOOM[1]

It is somewhat questionable as to whether a discussion of hybridization among mosquitoes has a place on this symposium, inasmuch as I know of no work that has been done on the inheritance of resistance to insecticides by these insects. My interest in hybridization between populations of mosquitoes has grown out of my earlier taxonomic studies and field experience, when it appeared to me that in order to understand more clearly the biology and the importance of mosquitoes as vectors of disease, it was necessary to think of these insects in terms of populations rather than as sharply divided, morphological species.

This is not the place for a comprehensive review of the work that has been done on mosquito genetics. Recently I have had an opportunity to examine such a review, prepared by Dr. James B. Kitzmiller. Even though comparatively little work has been done on mosquito genetics, the fact that Dr. Kitzmiller's manuscript contains over 150 pages shows that in our present discussion we shall not be able to do justice to the subject. As my contribution to this symposium I shall present certain problems involving speciation among the mosquitoes and some of the results we have obtained in our efforts to solve them; secondly, I shall illustrate the mechanisms of inheritance among the mosquitoes; and thirdly, I shall make some suggestions regarding the possible significance of these two aspects of mosquito genetics to the problem of insecticide resistance.

PROBLEMS IN SPECIATION AMONG MOSQUITOES.—It is necessary to refer first to the *Anopheles maculipennis* complex, which has been studied more thoroughly than any other group of mosquitoes. From the earlier work of Hackett, Missiroli, and others we know that what once was thought to be one or two species, is actually a group of at least seven species and subspecies. The cytological studies now being conducted by Dr. G. Frizzi suggests that in turn at least some of these species may be comprised of genetically distinct populations. Frizzi (1951) found that individuals of *Anopheles messae* from various sampling stations in the Province of Pavia might show a standard

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arrangement for the X chromosome, or "a very extensive and complex arrangement." The former arrangement was encountered more frequently in hilly regions, and the latter in the flat lands of the Po valley. It is interesting to note that Frizzi could find only a few naturally occurring heterozygotes, and suggested that sexual isolation might be a mechanism for keeping the two populations separated.

In North America there are five species which we consider as belonging to the *maculipennis* group. Of these, *Anopheles quadrimaculatus*, *freeborni* and *aztecus* have been colonized in the laboratory. Cross breeding experiments carried out by Dr. Ralph Barr have shown that there are distinct genetical barriers between these species, and that *aztecus* and *freeborni* are more closely related to one another than they are to *quadrimaculatus*. In a series of mating selection experiments, we obtained more conspecific than interspecific inseminations, except in the *aztecus* × *freeborni* combination, in which the *freeborni* males inseminated essentially the same numbers of both species of females (Rozeboom 1953). We may conclude therefore, that these mosquitoes represent distinct species, and that *freeborni* and *aztecus* are more closely related to one another than they are to *quadrimaculatus*. Much remains to be done on this complex in North America. The relationship of *A. earlei* and *occidentalis* to one another and to the first three species should be determined through hybridization experiments. It would be especially interesting to study populations within each species from various regions to determine whether there may be chromosomal differences such as those observed by Frizzi in the European forms.

There are several populations belonging to the *Culex pipiens* complex, the systematic positions of which are confused. *C. pipiens* has a holarctic distribution; and is also supposed to be present in East and South Africa; *C. quinquefasciatus* (=*fatigans*) is found throughout the tropics and subtropics; and *C. molestus* has a scattered distribution in North America, Europe, North Africa, and Australia. In addition, there are certain populations which seem to be intermediate between *pipiens* and *quinquefasciatus*, as for example, *C. pipiens pallens* of the Orient. We believe that we are dealing here with subspecific populations. We have shown in our laboratory that hybridization between North American *pipiens*, *quinquefasciatus*, and *molestus* occurs readily, and that hybrid populations can be maintained indefinitely without loss of vigor. We have been unable to find any physiological difference which would explain why, in North America, *pipiens* has a northern and *quinquefasciatus* a southern distribution. It seems likely that in the middle portion of the United States where the ranges of these two forms overlap, there may be considerable hybridization. Yet in general, these populations appear to maintain their identities in nature. There is a small difference in the structure of the male terminalia of *quinquefasciatus* which distinguishes this form from *pipiens* and *molestus*, and *molestus* is unique in its ability to lay eggs without having taken blood meals. Therefore, in the absence of any demonstrable genetic barriers, we were especially interested in determining whether barriers to crossmating might prevent indiscriminate intermingling of these forms in their natural environments. The results of our mating selection experiments (Rozeboom & Gilford 1954) have led us to conclude that the sexes of a given population are unable to recognize one another. There were, however, considerable differences in sexual activity; under identical laboratory conditions *molestus* was by far the most active, *pipiens* was least, and *quinquefasciatus* was intermediate. There was even a small difference between two strains of *quinquefasciatus*. It seems possible that although individuals within a population cannot recognize their own kind, differences in sexual activity might be a means of preventing complete blending in those areas where the ranges of two or more of the populations overlap. However, I do not believe that the results of these experiments warrant the conclusion that these populations are of more than subspecific status.

As an illustration of the complexity of this problem, one should refer to the work that Dr. Von H. Laven has been doing at Hamburg. He has studied four populations of *Culex molestus* from West Europe, three from North Germany, and three from South Germany. Whereas the populations within these regions are in

general interfertile, there are varying degrees of sterility between those from different regions (Laven 1953). Thus, whereas in Europe there are populations of *molestus* which appear to be separated by genetic barriers, and hence act towards one another as separate species, in North America *molestus* does not even seem to be specifically distinct from *pipiens* or *quinquefasciatus*.

THE *Aedes scutellaris* COMPLEX.—There are 18 species and subspecies within this group. The two which are of special interest to us are *Aedes polynesiensis* and *A. pseudoscutellaris*, as they are involved in the transmission of non-periodic filariasis. The widespread *A. polynesiensis* was formerly called *A. pseudoscutellaris;* recently Marks (1951) showed that the typical *pseudoscutellaris* was present only in the Fiji Islands, and she named the form with the extended distribution *A. polynesiensis*. The morphological differences between these two are very slight. Because of the similarity of the two forms, we were interested in determining whether hybridization between them was possible.[2]

The material from which our *Aedes polynesiensis* colony was established was collected on American Samoa by Lt. Leo A. Jachowski. *A. pseudoscutellaris* eggs were obtained from the colony maintained at the London School of Hygiene and Tropical Medicine, through the kind cooperation of Dr. H. S. Leeson. Crossbreeding experiments were carried out in 1-cubic-foot screen-wire cages. The females were fed on human blood; slices of apple were also placed in the cages as food for both the males and females. In setting up the hybridization experiments, about 40 males and 40 females were placed in each cage; one cage contained *polynesiensis* males and *pseudoscutellaris* females, another contained the reciprocal cross, and the third and fourth cages contained *polynesiensis* and *pseudoscutellaris* controls. Each adult *pseudoscutellaris* was examined microscopically for the presence of the characteristic white scales on the sides of the scutum before it was used in these experiments. Two hybridization experiments have been completed.

The total numbers of hybrid progeny obtained are given in table 1. These data are presented to show that we experienced no difficulty in establishing vigorous hybrid colonies. In both experiments these colonies were carried through the $F_3$ generation before they were discontinued. It should be pointed out that these figures do not represent the total numbers of individuals that could have been obtained. Only a few hundred of the eggs were set out to hatch, and many larvae and adults of each generation were removed for microscopic examination. The production of $F_1$ eggs was lower in the ♀ *pseudoscutellaris*×♂ *polynesiensis* cross. This was possibly due to the fact that the *pseudoscutellaris* females died more rapidly than did the *polynesiensis* females. No attempt was made in the first experiment to carry the control colonies beyond the $F_1$ generation, but in the second experiment, when such an attempt was made, the *pseudoscutellaris* control colony actually died out after producing only 155 $F_2$ eggs, while the other three colonies increased in size. The hybrid adults of both crosses appeared to be as vigorous as were the *polynesiensis* controls. We have evidence that the $F_1$ hybrid eggs of both crosses are less fertile than are those of the parent strains; from 8.0 to 31 per cent of the $F_1$ hybrid eggs hatched, as compared with 60 to 87 per cent of the $F_1$ control eggs. The $F_2$ and $F_3$ hybrid eggs were 24 to 77 per cent fertile.

**Table 1.—*Aedes polynesiensis*×*A. pseudoscutellaris:* total numbers of hybrid progeny (two experiments).**

| | ♀♀ POLY.×♂♂ PSEUDO. | | | ♀♀ PSEUDO.×♂♂ POLY. | | |
|---|---|---|---|---|---|---|
| | $F_1$ | $F_2$ | $F_3$ | $F_1$ | $F_2$ | $F_3$ |
| Eggs | 7129 | 9237 | 4995 | 1111 | 2512 | 5115 |
| Larvae | 738 | 3398 | 1046 | 228 | 1156 | 1464 |
| Pupae | 587 | 1974 | 685 | 191 | 812 | 948 |
| Adults ♀♀ | 357 | 410 | 222 | 90 | 317 | 227 |
| Adults ♂♂ | 185 | 782 | 326 | 70 | 374 | 269 |

Thus it is evident that *Aedes polynesiensis* and *A. pseudoscutellaris* are capable of producing vigorous hybrid populations. Before we can be sure that they represent subspecies rather than species, it will be necessary to determine whether there are barriers other than genetic ones which will keep them apart in Fiji, where the two forms are said to coexist.

MECHANISMS OF INHERITANCE.—It has been shown that the inheritance of some

[2] This work was aided by a contract between the Office of Naval Research and The Johns Hopkins University. The opinions expressed are those of the author and not necessarily those of the Navy Department. I am indebted to Mrs. Barbara N. Gilford for technical assistance.

characters is controlled by single recessive genes; these include pale coloration of the larvae and pupae of *Culex molestus* (Huff, 1929; Ghelelovitch, 1950), white eye color of adult *C. molestus* (Gilchrist and Haldane, 1947), and susceptibility of *C. molestus* to *Plasmodium cathermerium* (Huff, 1929). Ghelelovitch concluded that the inheritance of abdominal spotting in "*sternopunctatus*" and "*sternopallidus*" strains of *C. molestus* is complex and determined by several genes of unequal importance. Some workers have claimed that the autogeny may be dependent upon a single recessive gene, but published results do not support this conclusion too well. The intermediate structure of the terminalia of hybrids of *C. pipiens* and *C. quinquefasciatus* (Barr & Kartman, 1951) suggest that two or more genes are involved.

Some interesting results have been obtained in crossing of *Aedes aegypti* with *A. albopictus* (Bonnet 1950, Down & Baker 1949, Toumanoff 1939). For the most part, hybridization was successful only in one direction, with female *aegypti* and male *albopictus*, and the progeny resembled the female parent. In his hybridization experiments with *Culex molestus*, Laven (1953) was able to obtain fertile progeny when males from three populations from South Germany were crossed with females from three North German and four West European populations; but hybridization in the other direction was largely unsuccessful. Toumanoff (1950) and Laven suggest that the results of the *A. aegypti*×*albopictus* and *C. molestus* hybridizations could be explained on the basis of cytoplasmic inheritance.

RESISTANCE TO INSECTICIDES.—For the purpose of completing this discussion, we would like to have some data on the mechanism of inheritance of insecticide resistance in mosquitoes. Unfortunately, no information seems to be available at present. Several species have become resistant to DDT (Hess 1953), including certain populations of *Culex pipiens;* hence it might be possible to establish colonies in order to undertake studies on the inheritance of resistance.

There is another aspect of hybridization studies with mosquitoes that merits attention. This work has shown that we are dealing with dynamic, not static populations. Through mutations and adaptations, these populations should be capable of adjusting themselves to environmental changes. Species which have been especially susceptible to residual sprays in houses or other shelters, may be able to change their habits to avoid contact with the insecticide. We have some evidence that this actually may be occurring. In Panama, Trapido (1952) has found that *Anopheles albimanus* is again present in large numbers in the Chagres River Valley, although the houses are regularly sprayed with DDT. It seems that the adults are so irritated by DDT that they avoid lethal contact with treated surfaces. In Sardinia, a residual wild type population of *A. labranchiae* has resisted an intensive eradication campaign (Trapido & Aitken 1953). Even the highly domestic *A. darlingi*, which has been so susceptible to residual sprays in houses, seems to be composed of populations, some of which, in the interior of South America, are not easily controlled with residual sprays in houses (Bustamante 1951).

Changes in habits, plus inheritance of resistance to insecticides, may lead to the formation of mosquito populations which will be very difficult to control, especially in those areas where great reliance is placed on household residual sprays. Therefore, we believe that continued research on the nature of mosquito species may not only contribute towards evolutionary theory but may also have practical application in devising means of control.

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# The Genetics of Resistance to DDT in *Drosophila melanogaster*[1]

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Before undertaking the present project the author had been working with Dr. Bruce Wallace on the genetic behavior of populations under chronic irradiation (Wallace & King 1951, 1952; Wallace, *et al.* 1952) and quite naturally the problem was viewed from the start as one in population genetics. The first step in the study of resistance to DDT in Drosophila is the building up of resistant lines which means selection for resistance. Selection itself is a population phenomenon for it means changing the gene frequencies in the selected line—increasing those which produce the character selected for and decreasing those that weaken or mask it. So the program was drawn up with a set of underlying assumptions to which we had been led by our work with the irradiated populations.

Every population quickly establishes its own integrated genetic system. Any gene or group of genes present in high frequency has this frequency because it fits well with the other genetic material in the population. It gives, on the average, good viable zygotes when the chromosomes in which it is found are combined at random with others in the population. The various elements of the gene-pool are co-adapted.

The various co-adapted genetic elements maintain a dynamic equilibrium. A directional change in the frequency of one requires compensatory changes in the frequencies of others. By such an adjustment a new equilibrium as adaptively satisfactory as the old one may be reached but more often the new equilibrium is unstable or tends to shift back to the old one when the force producing the directional change—for example, artificial selection—is removed (Robertson & Reeve 1952, Reeve & Robertson 1952). This phenomenon is what Lerner (1950) calls "genetic homeostasis" and Waddington (1953), "normalizing selection." Thus response of the population to selection is influenced not merely by the scarcity or abundance of a gene or group of genes capable of producing the phenotype sought but also by the genetic system itself which may

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offer mild or intense resistance to an increase in the frequency of these genetic elements.

Selection acts on individuals—zygotes—by differential elimination or the production of differential fecundity. Neither genes nor chromosomes are selected directly. What are selected are pairs of chromosomes which give zygotes of the highest adaptive value. Hence those chromosomes are retained which have shown in past generations the highest probability of meeting, in the random combinations produced at fertilization, other chromosomes to which they are coadapted (Dobzhansky 1950, Dobzhansky & Levene 1951).

Since chromosomes are selected in pairs and two members of the pair are rarely identical, selection acts on heterozygotes and the behavior of any chromosome in homozygous condition has little influence on its selective value. The phenotype of a zygote is a result of the interaction of its two sets of chromosomes and every pair of chromosomes gives a characteristic level of expression of each phenotypic element characteristic of the population. This is another way of saying that most phenotypic characters in any population are polygenically determined (*Cf.* Mather 1949).

With these assumptions in mind a number of pertinent questions were formulated. (1) What is the observable process by which a population acquires resistance? Is the change sudden or gradual? Does the mean of the mortality curve merely shift or does the shape of the curve also change? (2) Is this process the same for all strains of a given species? (3) What is the effect of the level or selective intensity? Does it make a difference whether one lops off the 95 per cent of the population which is least resistant or merely eliminates the least resistant half? (4) Will different selected lines stemming from the same original stock respond to the same type of selection in the same way or are there alternative genetic pathways of arriving at the same level of resistance? (5) Will resistance decline if selection is relaxed? (6) What happens to resistance when different lines are crossed? e.g. a resistant by a susceptible or two resistant lines independently developed. In such crosses what will be the resistance of the $F_1$ and of subsequent generations? (7) What are the facts with respect to cross-resistance?

MATERIALS AND METHODS.—The experimental program has been set up in such a way as to give a maximum of information on these questions. Adult flies are treated with an aerosol of DDT dissolved in tributyrin. The aerosol is produced in a Vapo-nefrin glass nebulizer and led into a 1000 ml flask containing the flies. A 1 per cent solution is used and the dose is measured in minutes of exposure. At the end of the treatment an air stream is run through the flask for 1 minute to sweep out the aerosol. The flies are raised in half-pint milk bottles on a cornmeal-agar-molasses medium seeded with live yeast. Flies are shaken from the culture bottles on the thirteenth day after the eggs have been introduced and are stored in a new bottle containing medium for 24 hours before treatment. Flies from five culture bottles totaling about 1000 are treated together. There is no etherization before treatment. After treatment the flies are shaken into 2-inch glass tubes, 1 foot long, with gauze at the ends and a piece of photographer's sponge soaked in medium suspended inside. The tubes are placed in a humidifier at 75 per cent humidity on an angle of 15 degrees and left for 24 hours. The live flies are then etherized by placing pads soaked in ether at the ends and the live and dead flies are counted. Five time-doses are used 4′, 8′, 16′, 24′ and 32′. Ideally, each dose is repeated four times for each generation making a total of about 20,000 flies treated and 20 points on a mortality distribution.

All the selected lines have been set up from one of two different original stocks—one an Oregon-R laboratory stock, the other wild stock established by about 20 flies collected in a grocery store in Syosset, New York in July 1952. For the first year these stocks were maintained in mass cultures but since July 1953 they have been kept in cages where the population remains about 10,000. Originally 10 selected lines were established—four stemming from Oregon-R, six from Syosset. These were divided between three levels of selective intensity. At the highest level each generation is started by a single female which has survived a treatment where the mortality was above 95 per cent. At the intermediate level each generation is started by 10 females from a

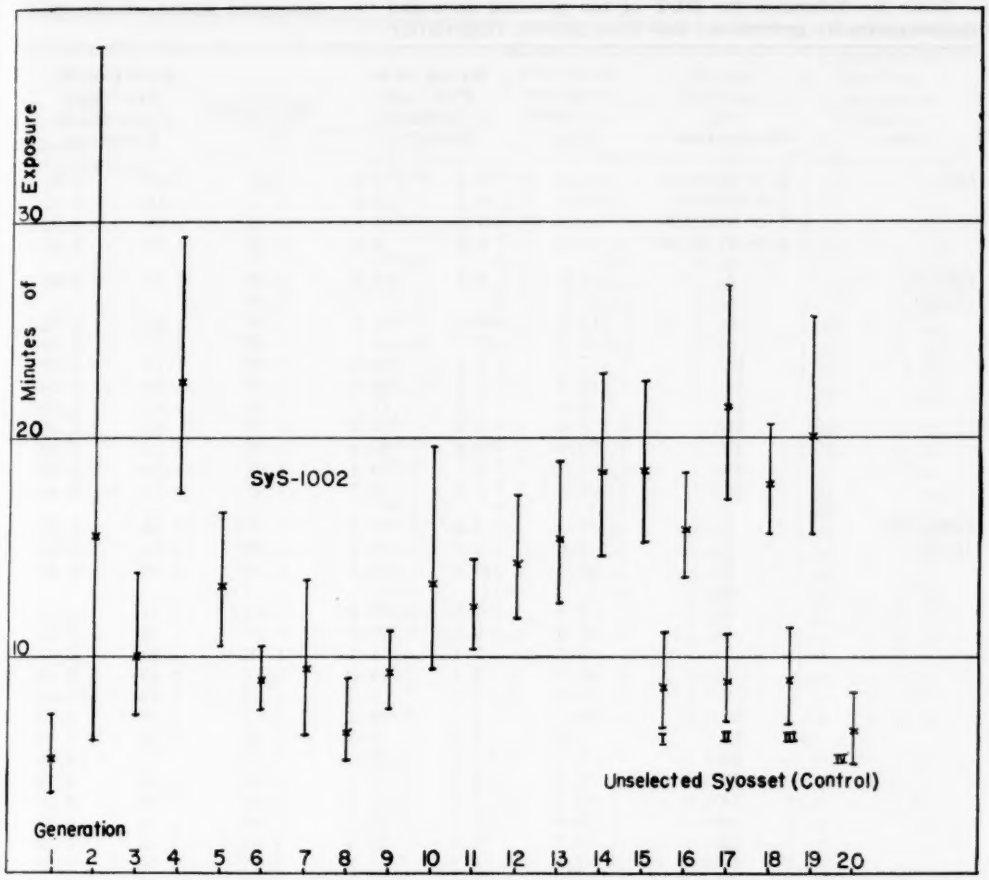


FIG. 1.—Graph showing $LD^{50}$ by generations and limits of the 95 per cent confidence intervals for SyS-1002 and control.

treatment killing over 90 per cent. At the low level all the survivors of a treatment killing about 50 per cent are used as parents. Duplicate lines at the three levels were set up in the case of the Syosset flies; the high and the low level Oregon-R lines were also duplicated. Since 20,000 flies are used to test one generation, it is impossible to run tests on every generation in the high and intermediate lines. Here the odd generation is untreated and is merely allowed to build up a population so that the even numbered generations can be treated. The parents of the generation to be treated are kept in a small cage and the eggs produced are divided among culture bottles in such a way that they yield about 200 flies per bottle. Control treatments of the two unselected stocks are made continuously in order to provide paired comparisons with the selected lines.

RESULTS.—Results have been analyzed using the Litchfield-Wilcoxon (1949) method of obtaining a regression line on a long probit plot from which one can read the $LD_{50}$ and the slope factor (S) which is a measure of the standard deviation of the mortality distribution. These figures with the ranges of their 95 per cent confidence intervals are given in table 1. The statistical procedure is a rapid simplified method approximating the more cumbersome maximum-likelihood analysis. It undoubtedly makes some sacrifices of accuracy, but since the data themselves have high variances and are sometimes characterized by erratic fluctuations, this method of analysis probably gives us as much information as one is justified in

**Table 1.—Tolerance for DDT of ten selected lines and two unselected stocks of *Drosophila melanogaster* by generations and time periods, respectively.**

| Line | Generation | $LD_{50}$[1] | Range of 95 Per Cent Confidence Interval | | Slope Factor (S)[2] | Range of 95 Per Cent Confidence Interval | |
|---|---|---|---|---|---|---|---|
| OR | 3/18–5/29/53 | 6.9 | 5.4 | 8.8 | 1.65 | 1.31 | 2.08 |
| | 6/2–7/23/53 | 9.2 | 6.1 | 13.9 | 1.57 | 1.16 | 2.11 |
| | 7/28–9/22/53 | 5.8 | 4.5 | 7.4 | 1.85 | 1.45 | 2.37 |
| | 9/28–11/30/53 | 4.4 | 3.6 | 5.4 | 1.99 | 1.53 | 2.58 |
| ORS-2 (High) | 2 | 6.6 | 2.9 | 14.9 | 1.57 | 1.03 | 2.39 |
| | 4 | 7.6 | | | 1.63 | | |
| | 6 | 12.3 | 10.8 | 14.0 | 1.59 | 1.42 | 1.78 |
| | 8 | 9.8 | 7.3 | 13.1 | 1.66 | 1.26 | 2.19 |
| | 10 | 7.9 | 5.1 | 12.2 | 1.62 | 1.11 | 2.37 |
| | 12 | 9.4 | 5.9 | 14.9 | 1.57 | 1.08 | 2.28 |
| | 14 | 9.6 | 7.9 | 11.7 | 1.51 | 1.30 | 1.75 |
| | 16 | 8.0 | 4.2 | 15.2 | 1.70 | .94 | 3.06 |
| | 18 | 13.0 | 8.8 | 19.2 | 1.81 | 1.19 | 2.75 |
| | 20 | 7.7 | 5.7 | 10.5 | 1.83 | 1.33 | 2.53 |
| | 22 | 8.3 | 5.3 | 12.7 | 1.93 | 1.15 | 3.24 |
| ORS-1001 (Low) | 1 | 6.4 | 5.2 | 7.9 | 1.71 | 1.44 | 2.03 |
| | 2 | 6.6 | 4.7 | 9.3 | 1.89 | 1.35 | 2.65 |
| | 3 | 12.4 | 8.3 | 18.5 | 1.73 | 1.18 | 2.53 |
| | 4 | | | | | | |
| | 5 | 9.8 | 7.8 | 12.3 | 1.68 | 1.31 | 2.15 |
| | 6 | 12.6 | 9.4 | 16.9 | 1.91 | 1.46 | 2.50 |
| | 7 | 9.6 | 8.1 | 11.4 | 1.69 | 1.43 | 1.99 |
| | 8 | 11.5 | 9.4 | 14.0 | 1.71 | 1.43 | 2.05 |
| | 9 | 5.8 | 5.1 | 6.6 | 1.55 | 1.42 | 1.69 |
| | 10 | 8.7 | 5.6 | 13.5 | 1.51 | 1.07 | 2.13 |
| | 11 | 7.4 | 6.2 | 8.9 | 1.48 | 1.29 | 1.70 |
| | 12 | 7.2 | 4.8 | 18.0 | 1.71 | .72 | 4.09 |
| | 13 | 6.2 | 5.0 | 7.7 | 1.75 | 1.45 | 2.12 |
| | 14 | 9.0 | 7.3 | 11.4 | 1.80 | 1.43 | 2.27 |
| | 15 | 9.6 | 6.1 | 15.1 | 1.95 | 1.13 | 3.35 |
| | 16 | 9.7 | 8.2 | 11.4 | 1.83 | 1.53 | 2.20 |
| | 17 | 7.8 | 6.8 | 8.9 | 2.11 | 1.76 | 2.53 |
| | 18 | 7.0 | 5.7 | 8.5 | 2.27 | 1.68 | 3.06 |
| | 19 | 9.8 | 7.7 | 12.5 | 2.04 | 1.57 | 2.65 |
| | 20 | 7.9 | 6.9 | 9.0 | 2.08 | 1.75 | 2.48 |
| Sy | (I) 11/15–12/5/52 | 8.6 | 6.7 | 11.0 | 1.70 | 1.34 | 2.16 |
| | (II) 6/1–7/21/53 | 8.8 | 7.0 | 11.0 | 1.57 | 1.13 | 2.18 |
| | (III) 7/22–9/24/53 | 8.9 | 6.9 | 11.3 | 1.78 | 1.35 | 2.34 |
| | (IV) 9/27–11/5/53 | 6.6 | 5.2 | 8.3 | 2.14 | 1.56 | 2.93 |
| SyS-1 (High) | 2 | 8.5 | 5.9 | 12.1 | 1.81 | 1.63 | 2.01 |
| | 4 | 13.3 | 12.3 | 14.4 | 1.92 | 1.86 | 1.97 |
| | 6 | 12.3 | 10.7 | 14.1 | 2.46 | 2.30 | 2.63 |
| | 8 | 15.5 | 11.6 | 20.6 | 2.67 | 2.30 | 3.09 |
| | 10 | 14.9 | 13.1 | 16.8 | 2.04 | 1.92 | 2.16 |
| | 12 | 13.5 | 9.5 | 19.1 | 1.96 | 1.75 | 2.19 |
| | 14 | 11.2 | 9.2 | 13.6 | 2.32 | 2.15 | 2.51 |
| | 16 | 13.5 | 12.3 | 14.9 | 1.87 | 1.81 | 1.93 |
| | 18 | 11.5 | 9.1 | 14.5 | 2.33 | 2.16 | 2.52 |
| | 20 | 11.1 | 7.4 | 16.7 | 2.53 | 1.27 | 5.06 |
| SyS-2 (High) | 2 | 8.8 | 7.2 | 10.7 | 1.98 | 1.55 | 2.53 |
| | 4 | 6.2 | 4.4 | 8.5 | 2.11 | 1.36 | 4.13 |
| | 6 | 8.0 | 5.3 | 12.0 | 2.07 | 1.34 | 3.19 |
| | 8 | 9.4 | 8.0 | 11.0 | 1.97 | 1.60 | 2.42 |
| | 10 | 14.0 | 10.1 | 19.5 | 2.41 | 2.07 | 2.79 |
| | 12 | 14.2 | 9.5 | 21.3 | 2.45 | 1.17 | 5.14 |
| | 14 | | | | | | |
| | 16 | 14.3 | 7.8 | 26.3 | 1.98 | 0.96 | 4.05 |
| | 18 | 24.2 | 16.1 | 36.3 | 2.10 | 1.60 | 2.75 |
| | 20 | 12.7 | 9.1 | 17.7 | 2.58 | 1.45 | 4.59 |
| | 22 | 9.7 | 5.3 | 17.6 | 2.20 | 0.98 | 4.95 |

| LINE | GENERATION | $LD_{50}$[1] | RANGE OF 95 PER CENT CONFIDENCE INTERVAL | | SLOPE FACTOR (S)[2] | RANGE OF 95 PER CENT CONFIDENCE INTERVAL | |
|---|---|---|---|---|---|---|---|
| SyS-102 (Intermediate) | 2 | 11.8 | 8.7 | 16.0 | 1.91 | 1.33 | 2.73 |
| | 4 | 21.2 | 18.3 | 24.5 | 2.03 | 1.67 | 2.45 |
| | 6 | 9.6 | 7.2 | 12.7 | 1.90 | 1.37 | 2.64 |
| | 8 | 12.7 | 10.4 | 15.5 | 1.77 | 1.35 | 2.31 |
| | 10 | 9.5 | 6.0 | 13.9 | 2.25 | 1.43 | 3.53 |
| | 12 | 13.8 | 11.0 | 16.3 | 2.10 | 1.55 | 2.83 |
| | 14 | 12.0 | 9.6 | 15.0 | 1.84 | 1.49 | 2.26 |
| | 16 | 17.4 | 12.7 | 23.8 | 1.94 | 1.34 | 2.10 |
| | 18 | 13.8 | 10.2 | 18.2 | 2.09 | 1.49 | 2.92 |
| | 20 | 14.8 | 12.0 | 18.2 | 2.19 | 1.68 | 2.84 |
| | 22 | 10.8 | 8.2 | 14.1 | 2.62 | 1.67 | 4.11 |
| | 24 | 10.2 | 7.6 | 13.7 | 2.27 | 1.49 | 3.45 |
| SyS-103 (Intermediate) | 2 | 6.2 | 4.4 | 8.8 | 1.88 | 1.30 | 2.73 |
| | 4 | 15.6 | 12.2 | 19.9 | 1.72 | 1.34 | 2.20 |
| | 6 | 8.0 | 6.7 | 9.6 | 1.87 | 1.48 | 2.36 |
| | 8 | 9.7 | 8.0 | 11.7 | 1.62 | 1.41 | 1.86 |
| | 10 | 10.7 | 8.0 | 14.2 | 1.96 | 1.38 | 2.76 |
| | 12 | 10.1 | 6.9 | 14.9 | 1.94 | 1.14 | 3.32 |
| | 14 | 12.0 | 9.2 | 15.7 | 1.91 | 1.46 | 2.50 |
| | 16 | 13.7 | 11.4 | 16.6 | 2.13 | 1.60 | 2.70 |
| | 18 | 15.8 | 11.8 | 21.2 | 1.92 | 1.30 | 2.78 |
| | 20 | 11.0 | 8.2 | 14.9 | 2.04 | 1.40 | 2.99 |
| | 22 | 7.1 | 6.0 | 8.4 | 2.38 | 1.79 | 3.17 |
| SyS-1001 (Low) | 1 | 7.0 | 4.2 | 11.6 | 1.68 | 1.02 | 2.77 |
| | 2 | 8.7 | 5.2 | 14.7 | 1.73 | 1.65 | 1.82 |
| | 3 | 14.9 | 9.3 | 23.8 | 1.82 | 1.08 | 3.06 |
| | 4 | | | | | | |
| | 5 | 13.2 | 9.9 | 17.7 | 1.74 | 1.25 | 2.41 |
| | 6 | 17.4 | 14.7 | 20.5 | 2.17 | 1.72 | 2.73 |
| | 7 | 9.0 | 6.6 | 12.3 | 2.00 | 1.38 | 2.90 |
| | 8 | 11.7 | 9.0 | 15.2 | 2.03 | 1.50 | 2.74 |
| | 9 | 13.0 | 10.7 | 15.7 | 1.88 | 1.50 | 2.35 |
| | 10 | 10.6 | 8.8 | 12.7 | 1.96 | 1.57 | 2.45 |
| | 11 | 14.0 | 12.0 | 16.4 | 1.76 | 1.48 | 2.09 |
| | 12 | 11.7 | 10.0 | 13.7 | 1.84 | 1.56 | 2.17 |
| | 13 | 21.0 | 16.8 | 26.3 | 2.29 | 1.59 | 3.30 |
| | 14 | 21.0 | 17.4 | 25.3 | 2.33 | 1.79 | 3.04 |
| | 15 | 21.6 | 18.3 | 25.5 | 2.22 | 1.89 | 2.60 |
| | 16 | 20.7 | 17.8 | 24.1 | 1.84 | 1.53 | 2.21 |
| | 17 | 18.0 | 14.9 | 21.3 | 2.37 | 1.78 | 3.16 |
| | 18 | 17.5 | 14.7 | 21.1 | 2.17 | 1.66 | 2.84 |
| | 19 | 19.3 | 14.5 | 25.7 | 2.18 | 1.46 | 3.23 |
| | 20 | 15.5 | 12.1 | 19.8 | 2.13 | 1.54 | 2.93 |
| SyS-1002 (Low) | 1 | 5.2 | 3.7 | 7.3 | 2.06 | 1.32 | 3.21 |
| | 2 | 15.4 | 6.2 | 38.0 | 1.89 | .71 | 5.04 |
| | 3 | 10.0 | 7.2 | 13.9 | 1.95 | 1.33 | 2.87 |
| | 4 | 22.6 | 17.4 | 29.4 | 2.02 | 1.46 | 2.80 |
| | 5 | 13.2 | 10.5 | 16.6 | 1.82 | 1.43 | 2.32 |
| | 6 | 8.8 | 7.5 | 10.4 | 1.84 | 1.51 | 2.24 |
| | 7 | 9.2 | 6.3 | 13.3 | 1.66 | 1.19 | 2.32 |
| | 8 | 6.4 | 5.2 | 7.9 | 1.94 | 1.53 | 2.46 |
| | 9 | 9.2 | 7.6 | 11.1 | 2.05 | 1.60 | 2.62 |
| | 10 | 13.5 | 9.3 | 19.6 | 1.96 | 1.58 | 2.43 |
| | 11 | 12.2 | 10.3 | 14.4 | 1.98 | 1.60 | 2.45 |
| | 12 | 14.3 | 11.7 | 17.4 | 2.27 | 1.69 | 3.04 |
| | 13 | 15.3 | 12.3 | 19.0 | 2.05 | 1.54 | 2.73 |
| | 14 | 18.4 | 14.7 | 23.0 | 1.96 | 1.56 | 2.47 |
| | 15 | 18.5 | 15.2 | 22.6 | 2.04 | 1.61 | 2.59 |
| | 16 | 15.8 | 13.6 | 18.3 | 2.29 | 1.85 | 2.84 |
| | 17 | 21.5 | 17.1 | 27.1 | 2.29 | 2.20 | 2.38 |
| | 18 | 17.9 | 15.6 | 20.6 | 2.56 | 2.02 | 3.25 |
| | 19 | 20.0 | 15.6 | 25.6 | 2.23 | 1.58 | 3.14 |

[1] $LD_{50}$ (mean tolerance) in minutes of exposure to aerosol of 1 per cent solution of DDT in tri-n-butyrin.
[2] The slope factor is the antilog of the reciprocal of the slope of the regression line; it expresses the fold change in dose required to produce a unit standard deviation change in response along the *regression line*.

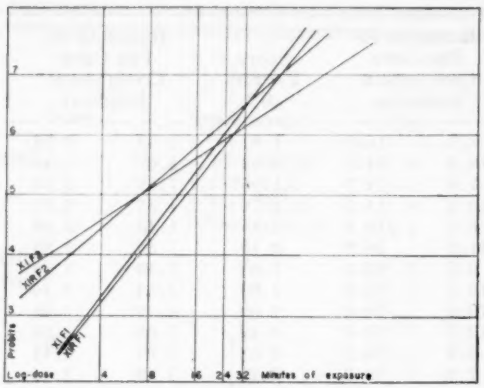


FIG. 2.—Regression lines on log-probit plot for mortality distributions of $F_1$ and $F_2$ of a cross made reciprocally between SyS-1001 F14 (resistant) and unselected Syosset. X1-SyS-1001 ♀♀ X1R-Sy ♀♀.

distilling from the data. One should keep in mind that neither the estimates nor their confidence limits can be regarded as having inspired precision.

Inspection of the table brings out a number of interesting facts. There is no significant difference in resistance between the two unselected stocks. The Oregon-R selected lines show no measurable response to selection and for this reason the two duplicate Oregon-R lines were discontinued at generations 16 and 18. Two of the Syosset lines have unquestionably developed resistance. SyS-1001 and SyS-1002 at generations 21 and 20 have $LD_{50}$'s of approximately 20′—about $2\frac{1}{2}$ times that of the control. These lines are carried at the low level of selective intensity. The data for SyS-1002 and the Sy control are shown graphically in figure 1. The Syosset lines carried at higher levels have not responded to the same degree; in fact their differences from the control are not statistically significant. They do, however, give rather consistently higher $LD_{50}$'s indicating an increase in resistance on the border line of our precision of measurement. The lines carried at the intermediate level show more evidence of response than those carried at the highest.

Two reciprocal crosses have been made involving resistant lines. One between SyS-1001 F14 and Syosset ($X_1$ SyS-1001 females, X1R Sy females) gave in $F_1$ $LD_{50}$'s of 12.5 and 13.6 respectively. These are about midway between the 21 and 8 of the parent strains. In the $F_2$ both $LD_{50}$'s had dropped to 7.0 which is not significantly different from the unselected stock. In the second cross made between SyS-1001 F18 and SyS-1002 F17 (X2 SyS-1001 females, X2R SyS-1002 females) the $LD_{50}$'s in the $F_1$ were 20.7 and 20.1, respectively, not significantly different from the parent strains. But in this case also the $LD_{50}$'s of the $F_2$ dropped drastically to 9.4 and 10.6. What is even more interesting—in both crosses the slopes of the regression lines shifted strikingly from $F_1$ to $F_2$ and in the same direction, indicating a greater variance or flatter distribution in the $F_2$. These data are shown graphically in figures 2 and 3.

DISCUSSION.—On the basis of the data accumulated some generalizations can be made. Resistance increases slowly under selection. Different stocks respond differently. The evidence is very strong that the character is polygenic, i.e., determined by a large number of interacting genes. It builds up in the population by slow increments. A low level of selective intensity is as effective, if not more so, than a high one. This indicates that in order to build up resistance one must maintain the genetic variability of the population at a high level. If resistance were produced by one or two genes of major effect, this would not be the case. This is not to say that in certain species or even in certain strains of *Drosophila melanogaster* such genes may not exist. They have not been found in the strains used and resistance can be built up in their absence.

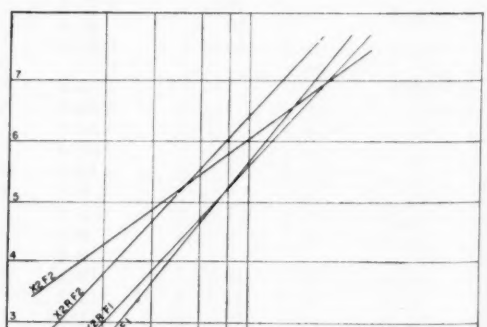


FIG. 3.—Regression lines on log-probit plot for mortality distributions of $F_1$ and $F_2$ of a cross made reciprocally between SyS-1001 F18 and SyS-1002 F17 (both resistant) X2-SyS-1001 ♀♀ X2R-SyS-1002 ♀♀.

But the most striking evidence for the polygenic nature of resistance lies in the behavior of the $F_2$ of the cross between two resistant lines. Here the sharp drop in the $LD_{50}$ and the greater variance of the distribution can hardly be explained without concluding that a large number of factors are segregating. The two lines stemming from the same stock and having been driven by selection to the same level of resistance must have picked out different genetic combinations. For when they are crossed, we observe in the $F_2$ a distribution of the phenotypic character which has a greater variance than it had in either line or even in the unselected stock.

Thus we can at this point give some partial answers to the questions raised in planning the program. The work is being continued and, we hope, future data may give us further insight into the problem.

SUMMARY.—A program of building lines of *Drosophila melanogaster* resistant to DDT has been carried through some 20 generations, treating adults by the aerosol method and breeding the survivors. Two different stocks have been used and lines have been distributed among three levels of selective intensity. One stock has shown no response; the other has developed increased resistance which is greatest at the lowest (50%) level of selective intensity. The $LD_{50}$ in two lines is between two and three times that of the control. Two crosses between different lines have given $F_1$'s intermediate in resistance and $F_2$'s of lower resistance and greater variance that the $F_1$'s. All the evidence indicates a complex polygenic system of genetic factors.

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# Analysis of a DDT-Resistant Strain of Drosophila[1]

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Earlier in this symposium Dr. King has reported on a study of the increase in DDT resistance in Drosophila under controlled conditions of laboratory selection. In our study the resistant strain was obtained by growing the flies in a population cage with varying intensities of selection in an attempt to duplicate to some extent the conditions under which a strain develops resistance in nature. This article is concerned with the genetic analysis of a strain obtained in this manner.

DEVELOPMENT OF DDT-RESISTANT STRAINS.—The selection took place in Teissier-type population cages with inside dimensions about 16×12×5 inches. (For a detailed description of this type of cage, see Wright & Dobzhansky 1946.) Each cage held 15 food-containing pans which were arranged so that they could be removed and replaced individually without

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an appreciable escape of flies. The pans were removed periodically in rotation and replaced with new ones containing fresh food, thus insuring a continuous food supply. Such a cage maintains a population of several thousand flies.

The selective agent was DDT applied to the inside surface of the cages. This resulted in the death of a large proportion of the adult flies, but after a few weeks the numbers were back up to the previous level. Then a higher concentration of DDT was added and so on for a period of about 3 years. The intervals between successive applications and the concentrations employed were studiously variable, the idea being to simulate nature more closely in this way. Temperature varied from 22 to 25° C.

The initial flies put into the cages were a heterogeneous mixture of wild Drosophila stocks and laboratory mutants to provide as wide a genetic base as possible for future selection. Within a very few generations mutants were no longer found, with two exceptions: (1) a cinnabar eye mutant persisted several months in one control culture, and (2) a forked bristle mutant was maintained for a similar period in the second selection cage. These mutants have been incorporated in the two stocks in the homozygous condition and serve as useful tools for the detection of contaminations with other flies or other experimental errors. Neither has any detectable effect on DDT resistance.

TESTING PROCEDURES.—All the data included in this report were obtained by testing 4-day-old adult flies. They were grown on a standard culture medium containing sugar, agar, yeast, peptone, cornmeal, and salts in half pint milk bottles. The flies to be tested were removed from their culture bottles daily so that every fly was less than 24 hours old, and were stored in fresh bottles for 3 days. On the third day the males and females were separated and were stored in groups of 20 of a single sex in shell vials. The following day the flies were tested with the insecticide. The only time that any fly was narcotized was at the time of separation of the males and females, at which time they were etherized.

The testing chambers consisted of shell vials in which a piece of DDT-treated filter paper had been inserted so as to cover the inside surface, except for the bottom and the cotton plug. (Special experiments showed no detectable difference in the mortality when these areas were also covered with DDT-treated paper.) The flies were shaken from their storage vials into the test vials, left for a specified period of time, and put back into food vials. Mortality counts were made 24 hours later. During the entire period of treatment and recovery, the flies were kept at 25° C. and about 65 per cent relative humidity. The DDT used was a purified product kindly supplied by E. I. du Pont de Nemours.

The filter papers were prepared by dropping a fixed amount of acetone solution uniformly over the area of the paper. The same total volume of solution was used in each case, variation in deposit being determined by varying concentrations of the DDT solution. The tests involved 14 concentrations, each twice the preceding, and ranging from 0.6 to 5120 gamma/cm.$^2$ of filter paper area. With a few exceptions the tests at all concentrations were run at one time on each group of flies to be compared. The entire experiment was replicated from 5 to 8 times, so that 100 to 160 flies were tested at each concentration and time. This procedure should help prevent confounding of uncontrolled temporal variations (of which there were many) with treatment or strain effects.

Tests were made on both sexes of flies. At all times and at all concentrations the females were uniformly more resistant. The data reported here are all from females, for two reasons: (1) the females seemed to give slightly more reproducible results, and (2) in subsequent tests in which chromosome makeup is studied, the females lend themselves to a neater analysis because of having the same number of X chromosomes as autosomes.

DOSAGE MORTALITY RELATIONS IN RESISTANT AND CONTROL STRAINS.—The first detailed comparison of the control strain and the strains from the two DDT treated cages was made after the cages had been in operation for 6 months. As can be seen from figure 1, the flies that had been in the cages had changed considerably in their DDT resistance. The selection for resistance in the two cages led to no detectable differences, so the data shown in figure 1 represent the pooled results from the two cages.

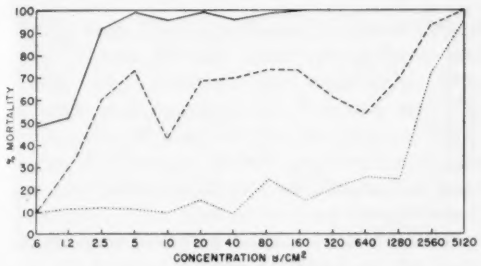


FIG. 1.—Dosage-mortality curves for 24-hour exposure of the control strain, the resistant strain after 6 months of selection, and after 3 years of selection. The concentration is the amount of DDT per square centimeter of filter paper. Data on females only. Control ——, 6 months – – –, 3 years · · ·

In this figure are also shown the results after 3 years of selection. The most striking feature of these curves is the slow rise in mortality with a tremendous inincrease in concentration. In all three strains there is very little change in mortality over a concentration change of several hundred fold. Measured in terms of $LD_{50}$ the selected strain after 3 years requires about 2000 times as much DDT as does the control strain.

Figure 2 shows data from the same three strains, but with 6-hour exposure to DDT instead of 24 hours. Here there is a sharp difference between the three strains as before, but the dosage-mortality curve is much steeper and more typical. The $LD_{50}$'s of the control and highly resistant strain differ by a factor of only about 6 rather than the factor of 2000 in the 24 hour test.

This is a striking illustration of the fact that the relative resistance of two strains of insects may depend on the way the measurements are made and be greatly different with different methods. In this case only the time of treatment and concentration were different. A statement

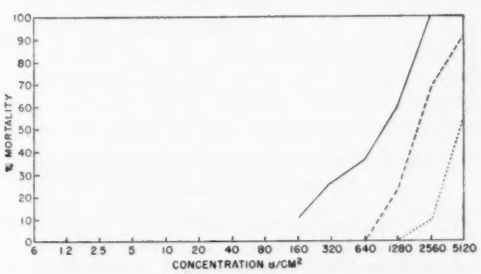


FIG. 2.—Dosage-mortality curves for 6-hour treatment. Control ——, 6 months – – –, 3 years · · ·

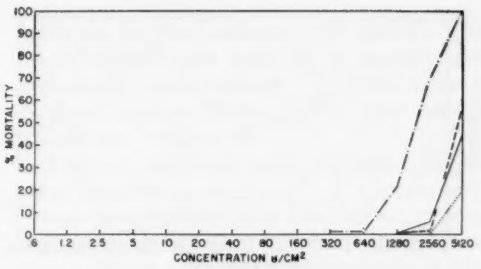


FIG. 3.—Dosage-mortality curves for 3-hour treatment. Control –·–·–, $F_1$ – – –, $F_2$ ——, resistant · · ·

that one strain is so many times as resistant as another thus means very little unless the conditions under which the comparison was made are specified.

On either scale the resistance changed about as much in the first 6 months of selection as in the next 3 years. This suggests that a considerable portion of the heritable variability was used up in the early part of the selection program.

TOPICAL TREATMENTS.—Because of its small size Drosophila has been difficult to treat topically. However 1 microliter drops of acetone are not lethal to the fly and it is possible to get reasonably reproducible results by using a topical treatment of this size. The $LD_{50}$'s were as follows: control males, .018 $\gamma$; resistant males, .073 $\gamma$; control females, .030 $\gamma$; resistant females, .127 $\gamma$. Thus the results from topical treatments show a ratio of $LD_{50}$'s of about 4:1 in the resistant and susceptible strains, being comparable to the short time treatments with filter paper.

RESISTANCE OF $F_1$ AND $F_2$ HYBRIDS.—Tests were made of the resistant strain selected for 3 years, the control, the $F_1$ hybrids, and the $F_2$ at 3, 6, 12, 18 and 24 hours. Figures 3, 4, 5, 6, and 7 show the dosage mortality curves for each of these.

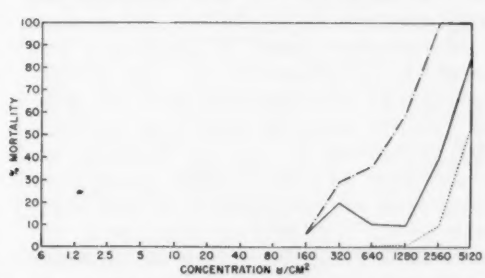


FIG. 4.—Dosage-mortality curves for 6-hour treatment. Control –·–·–, $F_2$ ——, Resistant · · ·

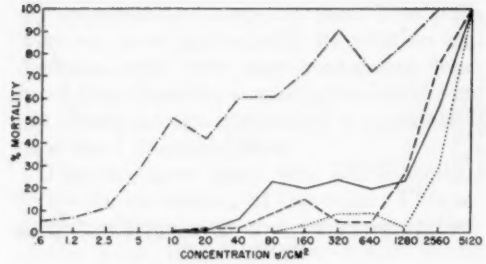


FIG. 5.—Dosage-mortality curves for 12-hour treatment.

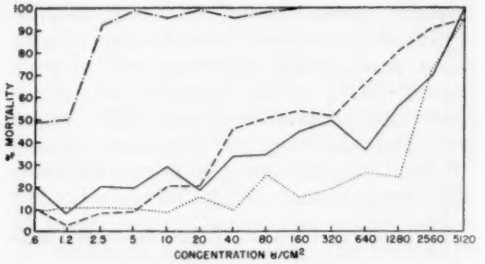


FIG. 7.—Dosage-mortality curves for 24-hour treatment.

Each point on the curves is based on 100 to 200 flies tested in groups of 20 as described previously. However, the uncontrollable fluctuations are large enough that only general trends can be regarded as meaningful.

These figures show the transition in general shape of the dosage-mortality curve as the time of 'reatment is varied. At short times (3 and 6 hours) the curves are fairly typical dosage-mortality curves with a steep slope. The hybrids are somewhat nearer the resistant parent, indicating some potence of the resistance factors. At 12 hours there is the beginning of a curve with a low slope. A concentration increase of about 1000 fold is required to go from a 5 per cent to a 95 per cent kill. The resistant parent again shows greater potence. The 18 and 24 hour curves show the tremendous difference in $LD_{50}$ in the two parents, due to the shape of the curve. The $F_1$ and $F_2$ are much nearer the resistant parent. As would be expected, in most cases the $F_2$ is nearer the mean of the two parents than the $F_1$. This suggests that there is some average dominance of factors for resistance.

The foregoing data suggest that resistance is polygenic, but offer no definitive evidence. However, an analysis using genetically marked chromosomes has confirmed this. A discussion of some of the consequences of a polygenic mode of inheritance has been given previously (Crow 1952).

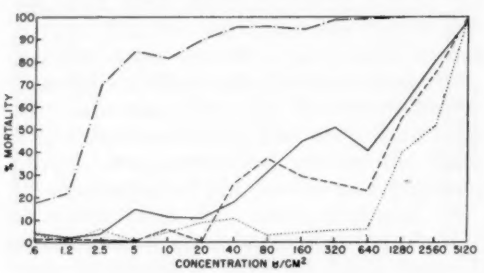


FIG. 6.—Dosage-mortality curves for 18-hour treatment.

ARE TWO PROCESSES INVOLVED IN RESISTANCE AT HIGH AND LOW CONCENTRATIONS?—The different character of the curves for long time (18 and 24 hour) treatment as compared with those for short time (3 and 6 hours) suggests that different processes may be involved in the resistance under the two conditions. Perhaps the genetic factors involved in long time low concentration resistance are different than those for resistance at short time and high concentration conditions. If so, they should be separable.

The fact that the ratio of $LD_{50}$'s in the resistant and control strains is over a thousand for long time treatment but less than 10 for short time is in line with this interpretation, since the selection in the cages where the flies were exposed for their entire adult lives would be much more comparable to the long treatment. Thus one might expect a higher level of resistance when measured under these conditions.

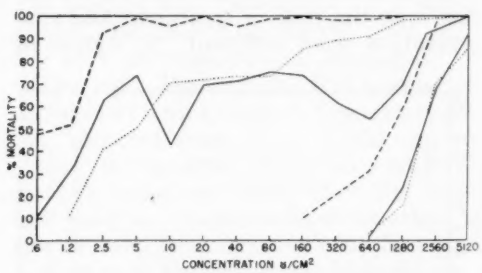


FIG. 8.—Dosage-mortality curves for the control strain (– – –), the selected strain after 6 months of selection for DDT resistance (———), and the same strain after 3 years absence from DDT (· · ·). The curves at the upper left are for 24-hour treatment; those at the lower right are for 6 hours.

To test this hypothesis, a non-resistant strain was divided into two groups and each was selected for resistance. One group was exposed for 3 hours and the other for 24 hours in the program of selection. Following a few generation cycles of selection a moderate resistance had been attained. The flies were then cross tested, each group being tested at 3 hours and at 24 hours. Those selected at 24 hour were just as resistant in the 3 hour test as those selected at 3 hours, and vice versa. (Griggs, unpublished.)

Therefore, it appears likely that the phenomenon observed in all this study is an intrinsic property of the dosage-response relationship of DDT effect in Drosophila, and that there are not separate genetic factors for resistance to long and short time treatments.

REVERSION TO SUSCEPTIBILITY.—An important question, both from theoretical and practical standpoints, is: Does a resistant population tend to become susceptible again when the selective agent is removed, and if so, how fast? If it were to be true that DDT-resistant flies return to susceptibility after a few generations in the absence of DDT it would point the way to the possibility of control of insects by intermittent or alternate use of insecticides.

Since the original population was not resistant to DDT, one must assume that the genes which result in DDT resistance were not initially advantageous—otherwise the population would already have been resistant. These considerations suggest that a population which has become resistant will again become susceptible when the DDT is removed, but they afford no idea whatsoever as to the rate at which this might occur. One can not make any estimate unless he knows how harmful the resistance factors are in the absence of the poison.

There is also the possibility that as resistance factors increased in the course of selection, modifying genes improving the viability of the resistance factors were also being accumulated, so that a stabilizing coadaptation would occur.

We carried out one test to determine whether our resistant strains would tend to become susceptible again when left without DDT. Periodically during the course of selection a sample of flies was removed and carried as a regular stock with no further contact with DDT. The stock which was selected 6 months for resistance was recently retested after a 3 year absence from DDT. The results are shown in figure 8.

Various authors have reported divergent results in this kind of experiment. Some have found rapid rates of reversion, and have shown that resistant insects are at a distinct selective disadvantage in the absence of the insecticide due to longer life cycle or other causes. Others have reported results such as ours. There is no reason to think that reversion rates should be the same in all stocks. In general selection for resistance, such as was carried out in our experiments and in nature where the insects are also exposed to strong selection for high viability and fertility in addition to resistance, would be expected to lead to strains with slow reversion. On the other hand laboratory experiments in the absence of natural selection would tend to accumulate some factors which increase insecticide resistance but are otherwise harmful, and would be expected to revert rapidly in the absence of the insecticide.

Aside from a possible slight effect showing at high concentrations in the 24 hour treatment, there was no difference in the flies immediately after 6 months of selection and 3 years later. The curves for 6 hour treatment are almost identical. That there was considerable genetic variability in the stock is shown by the fact that continued selection for DDT resistance resulted in continued increase in resistance. Thus the stability can not be due entirely to the genes being "fixed" by homozygosity. This means that the selective disadvantage of DDT resistance factors (in the absence of DDT) must be very slight, or that there has been some stabilization due to coadaptation. We hope to try to distinguish between these two hypotheses in future experiments.

SUMMARY.—A resistant strain of Drosophila has been developed by adding successively increasing amounts of DDT to the walls of the cage in which the flies were grown. When tested by exposure to DDT-treated filter papers for long times (18 to 24 hours) at relatively low concentrations, the resistant strain had an $LD_{50}$ about 2000 times that of the susceptible. On the other hand, when the tests were made at higher concentrations the dif-

ference in $LD_{50}$'s was only about six-fold. The striking difference in the two sets of results does not appear to be due to different sets of genetic factors coming into effect in resistance at different times and concentrations, since selection by means of 3-hour and by 24-hour exposures led to strains with indistinguishable resistance patterns. Analysis of the development of resistance and of the $F_1$ and $F_2$ hybrids suggests polygenic inheritance. No appreciable reversion to susceptibility took place in a resistant strain after 3 years without further contact with DDT.

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# Factors that Affect Insect Abundance[1]

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Factors affecting insect abundance are the primary concern of every field entomologist as the best methods of utilizing beneficial species or of controlling pest species can rarely be devised without a knowledge of the principles that underlie the fluctuations in the populations concerned. A substantial body of fact and philosophy bearing on these principles has been amassed and we are better prepared than ever before to undertake their further clarification. The subject cannot be adequately reviewed in one short paper. However, some salient features are discussed under "Working Concepts," "Examples from Current Work," and "Lines of Emphasis in Future Research."

WORKING CONCEPTS.—Nature functions as an indivisible complex in which no species of plant or animal exists in total isolation and no factor, physical or biotic, operates in complete independence. We cannot, therefore, divorce the broad ecological relationships of insects from the discussion of factors affecting their abundance. These broad relationships are reviewed in reference to primary habitat and taxonomic units, factors, balance of nature, and outbreaks.

*Primary units.*—Ecologists have long recognized the existence of a wide variety of plant and animal associations, and the term ecosystem (Tansley 1935) has been given to the complex of organisms and physical factors that together form a more or less distinct natural community. Examples of major ecosystems are: a woods, a meadow, a lake, a sand dune area. Such systems, of course, are not mutually exclusive since, for example, a species of insect, in its different developmental stages, may inhabit different communities, and predators may range widely through several such areas. In general, however, interrelations are stronger within ecosystems than between them and it is concluded by Elton (1949) that the minor habitats of an ecosystem form the primary habitat units for animal communities. Such minor habitats are represented by a tree, a group of shrubs, a glade in a woods, or a grassy hummock.

This primary habitat unit can readily be linked in our thinking with the primary taxonomic unit. Modern systematists (Mayr 1942, Mayr *et al.* 1953) regard all taxonomic categories, including the species and the subspecies, as heterogeneous, each being an assemblage of partially isolated local populations that are distinct genetically and therefore frequently distinguishable physiologically and morphologically. The *population* and not the species is recognized today as the basic taxonomic unit. The spatial arrangement of these populations differs for different species, but in general a minor

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habitat is occupied by a single population of each species represented in it.

Each natural community, or ecosystem, is thus composed of a complex of smaller, interlocking, dynamic systems: biological systems (within the organisms) interacting with one another and with the multiphased physical system that surrounds them. It is this web of interrelations that controls insect abundance.

*Factors.*—The factors that comprise this co-ordinating web may include quantities of energy in the form of light, heat, moisture, food, disease organisms, parasites, competitor species, etc.; environmental niches or inherent development and behavior patterns that confer various degrees of protection against such forces; and even man-made components such as insecticides. The importance of any given factor varies with time, place, species, stage of development, etc., i.e., its importance varies in relation to other factors that are concurrently active. It is not the individual factor, therefore, but the whole complex of factors that controls populations; and equivalent changes in insect abundance may arise from several different expressions of this complex.

Even though the factors function as a complex, certain of them may have a predominating influence on a population at a given time or place. Physical factors such as climate, weather, and space exercise an all-pervading effect: (1) by determining, in the absolute sense, what organisms can exist in a habitat; and (2) by affecting thresholds of activity and other biological behavior and thus influencing, often decisively, the importance of biotic forces. Nevertheless, when climatic conditions favor population increase, such biotic factors as predators, disease, and food supply may determine the upper levels of density attained.

Since the physical and biotic factors (*sens. lat.*) together comprise the whole ecosystem, it follows that when one set of factors predominates the other is correspondingly reduced in importance. Howard & Fiske (1911), followed by Nicholson (1933) and others, stress biotic factors, more specifically insect parasites and predators, as the principal, if not the only, regulators of the density of insect populations; Bodenheimer (1928), and later Uvarov (1931), attribute fluctuations in insect numbers primarily to the influence of climatic factors. Thompson (1929) sums up the importance of physical in relation to biotic factors as greatest in polar regions, deserts, and other barren places where physical conditions are unfavorable to life; and least in tropical rain forests and places where physical conditions tend to be uniformly favorable and life most abundant. Following this line of thought we may add that in an area occupied by an insect species physical factors probably exert a greater influence in the periphery, where population density is low, than in the optimum portions, where density is high.

These observations obviously relate to processes in the ecosystem that vary with changes in the density of the population itself. Smith (1935) describes as *density-dependent mortality factors* those components that destroy an increasing proportion as the population density increases as, for example, in many host-parasite relationships; and he describes as *density-independent mortality factors* those whose effect is not related to population density as, for example, excessive heat or cold, drought or rain. In general, biotic factors are regarded as mostly density-dependent and physical factors as mostly density-independent; but various combinations occur, further emphasizing the essentially dynamic and interdependent nature of the ecosystem.

*Balance of nature.*—Ecologists disagree over the interpretation and even over the admissibility of the "balance of nature" theory. The argument centers on (1) the emphasis given to a theoretical mean density about which the population fluctuates (Nicholson 1933, Smith 1935, 1939) and (2) the importance attached to biotic factors, especially intraspecific competition for food, in restoring the so-called steady density, or equilibrium (Nicholson 1933, 1947).

The concept of regular fluctuations oversimplifies the sometimes gentle, sometimes violent changes that characterize many field populations. As Solomon (1949) observes, ". . . many . . . population curves do not give the least impression that the fluctuations are related to the mean value. Movements towards the mean are often reversed before it is reached." It appears that the mean value or steady state is a mathematical interpretation that does not fit the biological

facts concerning the individual populations.

That competition for food is *the* mechanism that regulates abundance and restores the balance is not acceptable as a general concept. Undoubtedly density-dependent factors are frequently important and competition, in one form or another, may often predominate. This, however, should not obscure the facts that biotic factors always act in association with physical factors and that in such joint action the physical factors may also become density-dependent in their effects. One part of this effective complex should not be credited with the joint achievement. Furthermore, there are many situations in which competition for food does not appear to be a limiting feature of the habitat. Therefore, Nicholson's theory, as currently stated, fits only specific cases and fails as a general explanation.

Nevertheless, a broad type of balance or order in nature is obvious. It is not balance in the sense of equilibrium but rather as a changing state of *order* that results from the coexistence of interdependent forces that individually may vary, undergo modification, be added to, or be totally removed in the course of events. Hence, the expression "balance of nature" probably should be taken simply as a shorter way of saying: The ecosystem is whole; it functions as a complex of dynamic subsystems with an interdependence of parts that controls and directs all relationships; none of its components is constant, but their interrelations are such that excessive variation by any of them is ultimately checked by others, thus producing an elastic state of balance within which a state of flux prevails. In this sense, the ecosystem is always balanced though its constitutent populations may fluctuate widely.

*Outbreaks.*—An outbreak is simply an extreme upward fluctuation in the density of a single population living within a balanced habitat. During an outbreak the population is not out of control or unnatural or artificial, in the ecological sense, even when the outbreak may be attributed directly to man's intervention. Man is a natural creature who, like any other organism, lives in, utilizes, and modifies his environment with attendant natural consequences. That his effects are drastic does not justify excluding him from a consideration of community relationships. Natural laws must embrace all relevant natural phenomena. A discussion of insect outbreaks may, therefore, properly include reference to man-made epidemics.

de Gryse (1951), writing on forest entomology, states: "The final answer to the question 'What is the cause of insect outbreaks?' has not been forthcoming. It is more than likely that the solution of this problem will be found in a combination of causal relations and this will be different for every species of insect." With this we must agree. However, a few generalizations seem warranted.

Solomon (1949) concludes that "population variability tends to be inversely related to the degree of complexity of the ecosystem." This sums up the common observation that insect outbreaks occur more frequently in homogeneous than in mixed forests, and in large areas devoted to the production of one or a few related types of crop than in areas of diversified production. Since climate is a primary determinant of the nature of plant cover, these facts may be put on a geographic basis, complexity and stability of habitat decreasing generally from tropical through temperate to polar regions, with a corresponding increase in the probability of insect outbreaks. The accepted explanation is that an abundant or superabundant supply of food is assured to a limited number of phytophagous species and that their natural enemies suffer a reduction in efficiency through the loss of favorable relationships that exist only in the more varied habitats.

This may simply be another way of saying that any one condition affects different species in different ways and the more intensive or extensive the condition the more it is likely to promote an outbreak. The economic entomologist has witnessed this principle in action in innumerable instances as: (1) the widespread adoption of cultural practices such as strip-farming and combine-harvesting, which brought increased damage from the wheat stem sawfly, *Cephus cinctus* Nort.; (2) the occurrence of excessive quantities of flood-killed, wind-thrown, or fire-scorched timber, with consequent outbreaks of bark beetles and wood borers; and (3) the rise in prominence of phytophagous orchard mites following the general use of DDT.

The reference to DDT may more appropriately be included with a consideration of catastrophic factors. The term *catastrophic mortality factor* is applied by Ullyett (1947) to those forces that reduce the population of a host insect to insignificant proportions in a very short time. Bacteria, fungi, protozoa, and viruses that produce epidemics of insect disease are among the most important of the natural catastrophic factors. Drastic or sudden changes in weather or in other physical factors that result in a high percentage of deaths may similarly be classified. The application of chemicals and of sprays of disease organisms are examples from applied entomology. These factors do not normally exert a continuous effect, but a sudden and temporary one. They cause great changes and then virtually leave the scene. Parasites and predators may thus be reduced as drastically as phytophagous species, or even much more drastically; and in situations where natural enemies normally make an important contribution to the total host mortality, serious repercussions may follow. When the catastrophic factor has spent itself, the remnants of the host population begin to multiply and, in the absence of the density-dependent controlling factors, may rapidly reach destructive densities. In this way, catastrophic factors may be regarded as important contributory causes of outbreaks.

Weather has long been known as a primary influence holding in check many insect species with fantastically high reproductive potentials. This factor regularly eliminates enormous numbers of individuals under so-called normal conditions. Franz (1949) associates changes in population density with genetic variability in the population: weak physiological strains are normally destroyed, but under favorable conditions they survive and reproduce and eventually give rise to outbreaks; finally, lack of vigor permeates the whole population, which collapses from internal weakness especially when less favorable environmental conditions supervene. Wellington *et al.* (1950), on the other hand, lay the emphasis on the "relaxation of climatic control"; without this relaxation, destructive populations of the spruce budworm, *Choristoneura fumiferana* (Clem.), fail to develop even in the presence of an optimum food supply (Prebble & Morris 1951).

Finally, some outbreaks may be attributed to an evolutionary change that confers at least a temporary advantage on an insect species. For example, through natural selection a population can arise that is resistant or immune to the factor or factors that previously accounted for an important fraction of the total mortality in the species. The development of strains resistant to chemicals has been clearly demonstrated and the development of strains resistant to parasites and disease organisms is to be expected. Likewise, an important advantage may arise through the selection of a phytophagous strain with improved synchronization between its development and that of its host plant, as for example the remarkable phenological timing that exists between the emerging spruce budworm and the bursting of the male flowers of the balsam fir.

EXAMPLES FROM CURRENT WORK.—The more desirable trends in research may be indicated by brief reviews of three projects based in large part on field studies and illustrating (1) a small-habitat study without economic implications, (2) part of an extensive program with predictive and silvicultural objectives, and (3) a comprehensive investigation involving fungicides and insecticides as ecological factors in the community.

*Example 1.*—The primary habitat unit, or "minor habitat," as designated by Elton (1949) has already been mentioned. Varley (1947) throws some light on the inner workings of one such small community in his quantitative study of the insects living in the flower heads of the black knapweed, *Centaurea nigra* (L.) ssp. *nemoralis* (Jord.) Gugl. He sought an answer to the question: What factors control the population density of the Knapweed gall fly, *Urophora jaceana* (Hering)?

Three generations of galls were examined over a two-year period, a total of 92 square-meter samples being taken from approximately 500 sq. m. on which knapweed was abundant. In this small fragment of the ecosystem, Varley found 25 species of insects: 9 plant-feeding, 15 parasitic, one predaceous. He diagrammed a rather complex network of food relationships, but only five were really significant in affecting the numbers of the gall fly. By combining theory and measure-

ment he reached two major conclusions: "First, that in the census area the chalcid parasite, *Eurytoma curta*, was the factor primarily responsible for the control of the population density of the knapweed gall-fly, although it caused only a small proportion of the whole mortality. Secondly, that most of the remaining mortality factors, which together destroyed the greater portion of the gall-flies, had the long-term effect of increasing the average population density of the gall-fly. This was because they killed *E. curta* and the gall-fly indiscriminately, and hence reduced the efficiency of *E. curta* as a controlling agent."

It would be interesting to have additional minor-habitat studies made in the same ecosystem and to observe the interrelations that would surely be revealed. Likewise, it would be profitable to have further investigation of the same minor habitat over a wider geographic and ecological range to determine the general significance of the findings from the present limited study.

*Example 2.*—The spruce budworm, *Choristoneura fumiferana* (Clem.), has been studied intensively in both field and laboratory, expecially in Canada during the past 7 years. Although this native pest is highly destructive in cut-over areas, some of the severest outbreaks have occurred in virgin forests. A reconstruction of tree stands and budworm infestations in the past century has just been completed for a portion of northwestern Ontario to provide comparison with the more recent outbreak in the same area that has been under careful observation since 1945 (Blais 1954). It is now possible to compare the origin and spread of the current infestation with that of the early 1860's. Complementary studies on genetics, physiology, mortality factors, bioclimatology, and habitat relationships have significantly advanced our knowledge of this pest (Prebble & Morris 1951). The species thrives on the opening male flowers of mature balsam fir trees and outbreaks invariably begin in areas of concentration of this host. However, some areas of heavy balsam fir have escaped serious infestations in outbreak periods. There are numerous parasitic, predaceous, and pathogenic enemies.

The development of destructive budworm populations is explained on the basis of a relaxation of climatic control in areas of susceptible stands; and though the biotic agents also increase as the pest multiplies they do not appear to bring it under control until starvation and specific meteorological factors have reduced the population and exposed the survivors to relatively greater attack (Wellington *et al.* 1950, Prebble & Morris 1951). These observations reveal in striking fashion the interrelations of physical and biotic factors: one combination promoting population increase, a different combination causing decrease of the same species in the same locality. This study has recently been extended to include the long-term effect of a large-scale chemical control program (Flieger 1953).

*Example 3.*—In 1943, a highly significant series of investigations was initiated in the Annapolis Valley, Nova Scotia, to determine the long-term effects of spray chemicals on insect populations in apple orchards. A group of experimental orchards was used to study the effects of individual fungicides and insecticides, additional records being obtained from commercial orchards whose owners collaborated by applying recommended spray schedules. The project was undertaken to find an alternative to the constantly increasing spray program as a means of obtaining marketable fruit of good quality.

The approach has been ecological, embracing the whole insect fauna of the orchard and its environs and combining intensive field observation with field and laboratory experimentation. Emphasis has been upon the identification, life-histories, and behavior of entomophagous insects and mites and upon the effects of orchard sprays on their abundance and their interrelations with the four major pest species: the oystershell scale, *Lepidosaphes ulmi* (L.); the European red mite, *Metatetranychus ulmi* (Koch); the eyespotted bud moth, *Spilonota ocellana* (D. & S.); and the codling moth, *Carpocapsa pomonella* (L.). A beginning has been made on a study of the climatic factors involved and on the development of modified spray programs for trials by growers. Results and tentative conclusions have been presented in a series of papers (Pickett *et al.* 1946, Lord 1947, 1949, MacPhee 1953, Lord & MacPhee 1953, Pickett & Patterson 1953, MacPhee & Sanford 1954) and include the following:—

1. In general, parasites are most effective at densities of the pest species that are higher than can be tolerated economically, whereas general predators may be relatively influential at lower pest densities.

2. The predaceous thrips *Haplothrips faurei* Hood is a density-dependent factor in regulating phytophagous mite populations, but acts largely as a density-independent factor in regulating populations of the codling moth and the bud moth.

3. Phytophagous mites and aphids appear to form an important food reservoir for many predators and to be key factors in the interrelations that achieve natural control in orchards.

4. Natural control of the oystershell scale is accomplished by a parasite or a predator or both; but a physical factor, minimum winter temperature, determines which biotic agent exerts the greater influence in different parts of Canada.

5. Under conditions prevailing in Nova Scotia orchards, DDT, parathion, and sulphur drastically reduce the numbers of natural enemies; nicotine, lead arsenate, summer oil, *Ovotran*, *Phygon*,[3] and ferbam are lethal to some beneficial species and not to others, whereas cryolite, glyodin (Crag Fruit Fungicide 341), *Tag 331*,[4] and copper fungicides are relatively harmless to all important parasites and predators.

6. Many apple growers have adopted a modified spray program based on the results of these investigations and report general satisfaction even though in some cases insecticides have not been included in the spray schedule.

This comprehensive study illustrates well the complications that arise in the ecosystem from the addition of chemical factors. It also confirms the existence of two principles: the oneness of the factorial complex in the field; and the oneness of the science of entomology regardless of the epithets "fundamental" and "applied."

LINES OF EMPHASIS IN FUTURE RESEARCH.—The study of factors that affect insect abundance will probably spearhead the return of ecology as the field of major emphasis in entomology during the next decade. The success with which we meet this challenge will depend on how wisely we utilize the research resources that may be turned to this purpose. In this brief section I can do no more than introduce this important aspect of the subject.

From the experiences of the past 30 years we know that the estimating of insect abundance, though highly perplexing, is not nearly enough in itself. Numerical data must be related to physiology and behavior, which in turn depend, as we have seen, upon the interactions of internal and external forces, physical and biotic. Ultimately, then, we shall be required to measure concurrently many factors and to do this under natural conditions, the host population being but one of them. Once the basic concepts are established and accepted, progress will depend largely on our skill in devising adequate techniques.

However, before we reach the quantitative stage certain qualitative information is required. We cannot measure the fluctuations in abundance of a species until we know its life-history and basic behavior patterns and can find and recognize it in all its forms and stages. Furthermore, the measurement of physical factors is meaningless until we have established what needs to be measured and what limits of accuracy are required and possible. When refinements are expensive, we must appraise their necessity, as for example the need for measuring to a tenth of a degree a factor that influences an abundance that we can only estimate as scarce, common, or numerous. Finally, all quantitative data should be statistically adequate whether they are recorded simply as meaningful categories or as refined individual measurements.

In our endeavors to understand natural phenomena, we should use every possible approach: field observation, field and laboratory experimentation, theoretical considerations, surveys, and incidental records. Each has virtue. However, we must go to nature to study nature; hence skillful field observation is a continuing requirement. It is an art that warrants further development and greater use. However, to unravel the interrelations that affect insect abundance, selected problems must be taken to the laboratory for analysis under controlled conditions. But what is undertaken in the laboratory should arise

[3] 2,3-Dichloro-1,4-naphthoquinone, a product of the U. S. Rubber Co.
[4] Phenyl mercury salts in mixture.

from what is observed in the field. Furthermore, we must recognize from the start that the laboratory is a novel habitat. In it populations that co-exist in the field are separated and interacting natural factors are isolated. Such an experiment will supply factual information, but it is factual only in reference to its own universe—the laboratory. The information thus obtained can be used to develop theories, but the theories require successful testing in the field before we can accept them as principles.

Yet theories and concepts are useful; they assist in orientation and planning. But theories derived from simple or restricted biological systems such as a culture of the confused flour beetle, *Tribolium confusum* Duv., have limited application to field ecology, as also have formulae that employ mathematical constants to represent inconstant biological phenomena. The relation of biomathematics to insect population problems has been discussed by Thompson (1939) and more recently in a comprehensive paper by Ullyett (1953), who concludes: "The theories of Lotka, Volterra and Nicholson and Bailey, being all based on the primary assumption that animals act at random in relation to the things which are important for their survival, must be rejected as adequate general theories of animal behaviour." Undoubtedly, we should proceed with caution in deciding what fraction of our resources should be devoted to experiments based on mathematical concepts that are derived largely from mathematics or physics instead of from adequate biological data.

Increased attention is warranted in field experimentation. In Schneirla's words (1950): "It should be possible to carry many of our laboratory methods into a direct-manipulative use in the field, with appropriate modifications." This was imaginatively executed by Brown (1952), who constructed "dummy men" for testing under controlled conditions in the field the validity of his laboratory findings on individual factors affecting the attractiveness of humans to mosquitoes. In general, field investigations must be thoroughly planned and the individual assignments carefully limited or the project becomes diffuse and unwieldy and, eventually, unprofitable. Furthermore, if the specific and limited assignments are to yield more than specific and limited results, they must be wisely selected and skillfully integrated into a combined picture of general significance.

RECAPITULATION.—In this paper I have sought to depict each natural community as a plastic but balanced system of variable factors and each insect population as one of the unstable components. The density of such a population at any given time is a product of the interactions of all concurrently active factors, each of which differs in time and space in its effectiveness. Fluctuations in insect abundance thus arise from different causes and tend, therefore, to be irregular in their occurrence. It is extremely difficult to appraise the individual significance of factors that never act independently in nature. But the need for such appraisal is upon us. Indeed, the effects of pesticides on the food-producing and fibre-producing ecosystems of the world seem to have already touched off a new era in field ecology. This may well be the great entomological challenge of the century.

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# Urban Fly Dispersal in the Area of Savannah, Georgia

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During the past decade there has been an increasing interest in municipal fly control in the United States, which was stimulated by the early success of DDT in controlling flies and the demonstrated effect of fly control in reducing diarrheal disease (Watt & Lindsay 1948). To approach the problem of municipal fly control adequately, whether by sanitation or chemical means, or both, basic information must be available on the breeding and flight habits of flies in present-day urban areas. Studies by Quarterman *et al.* (1949) developed some data on the flight dispersion of a laboratory-reared, mutant strain of *Callitroga macellaria* in urban areas. Studies by Bishopp & Laake (1921) and Lindquist *et al.* (1951) produced valuable information on the flight range and habits of several species of flies under certain conditions in rural areas, and indicated that flies released in rural areas may pass completely over urban areas in their flight. Earlier investigations by Parker (1916) in Montana had shown that house flies would travel 2 miles in urban areas. These previous studies left much to be desired concerning the knowledge of fly dispersal habits in urban areas, however, and the

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investigations described herein were undertaken to provide additional information on this subject.

PROCEDURE—These studies were made in Savannah, Georgia, a city of approximately 130,000 population, which contains typical areas normally found in most American cities. Before selecting the points for making the fly releases, the city proper and its immediate suburbs were surveyed rapidly and each block or section was classified for the purposes of these studies as low, middle, or high class residential areas; business district; industrial section, and open or wooded areas; and sites having high fly production potential in suburban areas were noted.

In the first flight dispersion test conducted in June 1951, four release points were selected. One was in the center of a high class residential area; one at the junction of a high, middle, and low class residential area; one in a business section surrounded by industrial, open, and low class residential areas; and one in an open area surrounded by open, industrial, low, and middle class residential areas.

To minimize the possibility of affecting the tendency of the flies to migrate, which might result from artificially overcrowding the release points by introducing abnormal populations, the test flies were obtained by trapping wild adult flies at the four sites selected as the release points, by placing several baits around the premises and trapping the flies with a screen pyramid-shaped trap. The trapped flies were counted and classified at the time of capture, and were fed for approximately 24 hours on milk containing radioactive substances at the rate of 1 microcurie of radioactive material per milliliter of milk, a concentration which had been shown to be satisfactory for tests of this type by the laboratory investigations of Jensen & Fay (1951). Phosphorus-32, calcium-45 and iodine-131 were used to tag the flies, those at two of the release points being marked with phosphorus-32. The flies at one of these two points were dusted with Rhodamine B[2] just before release.

On the evening of June 2, after it had become too dark for them to migrate, the flies were released simultaneously at the same points where they had been trapped. This time for release was selected to minimize the possible effects of the temporary caging. At daylight the next morning, the flies were in their normal environment and presumably would resume their activities in a normal manner.

Conventional cone-shaped fly traps were used to recover the released flies. Traps were placed in concentric circles approximately 0.25, 0.5, and 1 mile around each release point. The four release points were so situated that these circles met or overlapped each other. A few additional traps were added around the periphery of the city to complete the pattern of trap locations.

The recovery traps were baited with ground fish heads diluted 1:1 with water. Baits were placed in the traps at daylight on the morning following the release of the tagged flies, and the first trap catches were collected beginning at noon on that same day. The trapped flies were collected daily except on week ends, when the traps remained in operation from Friday to Monday without the flies being removed from them. The trapped flies were killed in a metal chamber with Cyanogas A-dust and examined in the laboratory with a Geiger counter for tagged flies. At the release point locations, the traps were operated for only about an hour each day to obtain data on the percentage of marked flies present in the total fly population at those sites from day to day.

The radioactive calcium and iodine were tried without benefit of prior laboratory studies. The calcium was in the form of calcium chloride and apparently affected the flies adversely. Approximately half of them which fed on the milk containing the calcium were dead by the time for release, and later laboratory tests (Jensen & Fay 1951[3]) showed this material to be unsatisfactory due to the high mortality it produced and its rapid excretion by the flies. The iodine also produced considerable mortality among the male flies. Flies tagged with phosphorus and iodine were separated on the basis of differences in types of emissions. A shield stopped the phosphorus beta particles while the more penetrating gamma rays were admitted to the Geiger counter. The recovered flies which had been tagged with phosphorus were placed on white filter paper and a drop of acetone was added to each fly. The acetone dissolved the dye from those dust-

[2] A product of Eastman Kodak Co., Rochester, N. Y.
[3] Unpublished data.

**Table 1.—Number of marked flies released and recovered in a dispersal test at Savannah, Georgia, June 1951.**

| RELEASE POINT | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* SPP. | *Scarophaga* SPP. | OTHER SPP. | TOTALS |
|---|---|---|---|---|---|---|
| I | 1,000 | 30 | 100 | 4 | 4 | 1,138 |
| II | 1,950 | 350 | 185 | 140 | 25 | 2,650 |
| III | 600 | 2,500 | 400 | 50 | 50 | 3,600 |
| Total released | 3,550 | 2,880 | 685 | 194 | 79 | 7,388 |
| Total recovered[1] | 27 | 56 | 9[2] | 2[3] | 0 | 94 |
| Per cent recovered[1] | 0.8 | 1.9 | 1.3 | 1.0 | 0 | 1.3 |

[1] Does not include recoveries of marked flies at their respective release points.
[2] All *Phaenicia* spp. recovered were identified as *P. sericata*.
[3] One specimen identified as *S. haemorrhoidalis* and one as *S. impar*.

ed with Rhodamine B and the color was easily detected on the filter paper upon evaporation of the acetone.

A second release test was conducted in July, using the same four release points within the city that were used in the first test. In addition, four other release points were selected at high fly-producing sites outside the city limits. One of these was the city dump, two were dairies, and one was an abattoir. The techniques for obtaining, marking, releasing, and recovering the flies in this second test were the same as those employed in the first test, except that only phosphorus-32 was used to tag the test flies radioactively. In addition, the flies were dusted with a different dye for each release point just prior to release. The following dyes were used for this purpose: Rhodamine B, Calco oil orange 7078-V,[4] Calcogas green 0-9660 special,[4] Calco oil yellow ZG concentrate,[4] Calcogas violet special,[4] Calco oil red N-1700,[4] Calco oil black B-3804,[4] and Auramine O.[5]

The test flies were originally trapped as adult flies on July 9 and 10, fed on milk containing P-32 for 24 to 48 hours, and released after dark on the evening of July 11. Recovery traps were located within the city at the same locations used in the first test. Several additional traps were placed in outlying areas around the city and between the four new release points and the city proper. The trapping schedule was the same as that used in the first test.

Tagged flies were removed from the trap catches in the laboratory with the aid of a Geiger counter, and were washed with acetone to determine the color of dye present on them. It will be noted that two red and two yellow dyes were used. One of each of these colors, Rhodamine B and Auramine O, was fluorescent, which made it possible to distinguish between them.

RESULTS.—The unsatisfactory performance of the calcium-45 used to tag the flies at release point IV in the first test resulted in the complete loss of dispersal data for these flies. Although a high mortality occurred among the male flies tagged with iodine-131 at release point III, there was sufficient survival that a number of iodine-marked flies were captured in the recovery traps. Table 1 shows the number of marked flies released at the three release points, the number of each species recovered, and the percentage of recovery. The percentage of recovery was greater for blow flies than for house flies, especially for *Callitroga macellaria*.

The various distances at which recoveries of marked flies were made are shown in table 2. It will be noted from this table that most of the marked flies were recovered within one-half mile of their respective release points, except *Callitroga macellaria*, which dispersed over greater distances, the majority of that species being recovered between 1 and 3 miles from release points.

An interesting feature of this study was the fact that on the first day after release, recoveries were made at the maximum distance for house flies and at near maximum for *Phaenicia* and *Callitroga macellaria*. *Phaenicia sericata* was recovered 1.25 miles from the release point after 7 daylight hours following release; *C. macellaria*, 3 miles in the same period; and *Musca domestica*, 1.75 miles in 10 hours. Only one specimen each of *C. macellaria* and *Phaenicia* was recovered later at dis-

[4] A product of Calco Chemical Division, American Cyanamid Co., Bound Brook, N. J.
[5] A product of Biolsol Products Co., Rochester, N. Y.

**Table 2.—Recovery of marked flies at indicated distances from release points in a dispersal test at Savannah, Georgia, June 1951.**

| Distance of Recovery Traps from Release Points in Miles | Number of Traps[1] | Average Number Marked Specimens Recovered per Trap | | | | |
|---|---|---|---|---|---|---|
| | | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* Spp. | *Sarcophaga* Spp. | All Species |
| 0.25 | 12 | 1.08 | 0.08 | 0.50 | 0.00 | 1.67 |
| 0.50 | 14 | 0.86 | 0.22 | 0.07 | 0.15 | 1.29 |
| 1.00 | 20 | 0.05 | 0.30 | 0.05 | 0.00 | 0.40 |
| Total 0 –1.0 | 46 | 0.57 | 0.22 | 0.17 | 0.04 | 1.00 |
| 1.1–2.0 | 43 | 0.02 | 0.58 | 0.02 | 0.00 | 0.63 |
| 2.1–3.0 | 58 | 0.00 | 0.34 | 0.00 | 0.00 | 0.34 |
| 3.1–4.0 | 6 | 0.00 | 0.17 | 0.00 | 0.00 | 0.17 |

[1] A total of only 52 traps were used, but each trap in most instances was located at a different distance from each release point and served as three "traps" for the purposes of this table.

tances greater than those of the first day, and these additional distances were small.

The data in table 3 show the relationship between the different types of urban areas and the recovery of marked flies. House flies were recovered primarily in residential areas and "hot spots." These latter included two horse stables and one pig pen. *Phaenicia* were relatively well distributed in all areas. *Callitroga macellaria* were recovered also in practically all areas, with the greatest numbers being taken in vacant and low class residential areas. The distinction between recoveries in high and middle class residential areas was not very great, but as between these and the other types of areas there were noticeable differences, with larger numbers of flies being recovered in these other areas. These differences were brought out more sharply in the second release test.

The numbers of marked flies recovered at their respective release points, where the traps were operated only 1 hour each day, were small at points I and III. One marked house fly was trapped at point I on the first, second, and ninth day after release, and one *Phaenicia sericata* on the fourth day. The one marked specimen was the only house fly trapped at this point on the first day after release. At release point III, two marked *P. sericata*, and one *Callitroga macellaria*, were recovered on the day following release, and one *C. macellaria* each on the third and fifth days. At release point II (a horse stable), 71 marked house flies and 1 *P. sericata* were trapped the first day after release, none on the second day, and a total of 5 more marked house flies on the third to the fifth days. The low recoveries of marked flies at the release points after the first day were strong indication that all species were moving about freely. The greater

**Table 3.—Distribution of recoveries of marked flies in the various types of urban areas in which traps were located in a dispersal test at Savannah, Georgia, June 1951.**

| Location of Traps | Number of Traps Operated | Number Recovered | | | | | | Average Number per Trap | | | | | | Per Cent Traps Catching Tagged Flies | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* Spp. | *Sarcophaga* Spp. | Other Spp. | Total All Species | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* Spp. | *Sarcophaga* spp. | Other Spp. | Total All Species | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* Spp. | *Sarcophaga* Spp. | Other Spp. | All Species |
| High class residential | 8 | 5 | 1 | 2 | 0 | 0 | 8 | 0.6 | 0.1 | 0.3 | 0.0 | 0 | 1.0 | 25 | 13 | 25 | 0 | 0 | 38 |
| Middle class residential | 11 | 3 | 3 | 0 | 0 | 0 | 6 | 0.3 | 0.3 | 0.0 | 0.0 | 0 | 0.5 | 18 | 27 | 0 | 0 | 0 | 45 |
| Low class residential | 15 | 15 | 14 | 3 | 2 | 0 | 34 | 1.0 | 0.9 | 0.2 | 0.1 | 0 | 2.3 | 27 | 40 | 13 | 13 | 0 | 47 |
| Vacant | 10 | 0 | 33 | 1 | 0 | 0 | 34 | 0.0 | 3.3 | 0.1 | 0.0 | 0 | 3.4 | 0 | 50 | 10 | 0 | 0 | 50 |
| Industrial | 3 | 0 | 5 | 1 | 0 | 0 | 6 | 0.0 | 1.7 | 0.3 | 0.0 | 0 | 2.0 | 0 | 66 | 33 | 0 | 0 | 100 |
| Business | 2 | 0 | 2 | 3 | 0 | 0 | 5 | 0.0 | 1.0 | 1.5 | 0.0 | 0 | 2.5 | 0 | 50 | 50 | 0 | 0 | 50 |
| "Hot spots" | 3 | 7 | 0 | 1 | 0 | 0 | 8 | 2.3 | 0.0 | 0.0 | 0.0 | 0 | 2.7 | 67 | 0 | 33 | 0 | 0 | 100 |

**Table 4.—Number of marked flies released and percentage recovered in a dispersal test at Savannah, Georgia, July 1951.**

| | Release Point Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | Totals |
| *Musca domestica:* | | | | | | | | | |
| No. released | 330 | 4,070 | 1,200 | 260 | 7,000 | 10,000 | 12,000 | 5,230 | 40,090 |
| Per cent recovery away from release point | 3.3 | 1.1 | 0.3 | 1.9 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| Total per cent recovery[1] | 3.9 | 2.2 | 0.4 | 1.9 | 0.4 | 3.1 | 2.3 | 0.6 | 1.8 |
| *Callitroga macellaria:* | | | | | | | | | |
| No. released | 770 | 990 | 2,000 | 3,580 | 900 | 100 | 500 | 2,190 | 11,030 |
| Per cent recovery away from release point | 2.3 | 2.2 | 2.7 | 3.2 | 0.7 | 6.0 | 1.8 | 2.2 | 2.5 |
| Total per cent recovery[1] | 2.3 | 2.3 | 2.7 | 3.2 | 0.8 | 6.0 | 1.8 | 2.3 | 2.6 |
| *Phaenicia* spp.: | | | | | | | | | |
| No. released | 20 | 80 | 600 | 100 | 2,000 | 15 | 25 | 25 | 2,865 |
| Per cent recovery away from release point | 0.0 | 3.8 | 1.7 | 3.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.6 |
| Total per cent recovery[1] | 0.0 | 3.8 | 1.7 | 3.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.8 |
| *Sarcophaga* spp.: | | | | | | | | | |
| No. released | 30 | 200 | 50 | 315 | 0 | 0 | 25 | 25 | 645 |
| Per cent recovery away from release point | 3.3 | 1.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 |
| Total per cent recovery[1] | 3.3 | 1.0 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 |
| Other spp.: | | | | | | | | | |
| No. released | 120 | 110 | 50 | 20 | 100 | 0 | 1 | 5 | 406 |
| Per cent recovery away from release point | 1.7 | 0.0 | 2.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Total per cent recovery[1] | 1.7 | 0.0 | 2.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |

[1] Includes recoveries at release point.

percentage of recovery, the greater distances over which they were trapped, the wider variety of areas in which they were recovered, and the high recoveries in vacant areas demonstrated stronger migratory habits in *C. macellaria* than were exhibited by house flies, *Phaenicia* or *Sarcophaga*.

Table 4 shows the number of marked flies released at the eight release points used in the second dispersal test, and the percentage recovery. The recovery was slightly higher in the second test for the three release points which were common to both tests. Thirty-four per cent of the recovered house flies were trapped beyond 1 mile from their release points (Table 5), as compared to only 4 per cent in the first test. Twenty-four per cent of the recovered *Phaenicia* and 50 per cent of the recovered *Sarcophaga* were trapped beyond 1 mile in the second test, compared to 11 per cent and none, respectively, in the first test. Conversely, only 59 per cent of the recovered *Callitroga macellaria* were trapped beyond 1 mile in the second test, as compared to 82 per cent in the first release.

In considering the recovery of the marked flies relative to the distance of recovery from the release points, consideration must be given to the fact that the areas immediately adjacent to the release points were more intensively trapped than those farther removed. For example, the fact that 66 per cent of the recovered house flies were trapped within 1 mile of the release points in the second dispersal test does not mean that 66 per cent of the released flies remained within the 1-mile area after their release. There were fewer traps operated per unit area of land outside the 1-mile zone. If the average number of marked flies recovered per trap in each zone were multiplied by a correction factor to equalize all traps on the basis of land area served, the figures would indicate that most of the flies moved into the areas beyond the 1-mile zone. In fact, such an adjustment indicates no more than a slight reduction in total numbers of flies that must have migrated up to 4 miles or

**Table 5.—Recovery of marked flies at indicated distances from release points in a dispersal test at Savannah, Georgia, July 1951.**

| Distance of Traps from Release Points in Miles | No. of Traps[1] | Average Number of Marked Specimens Recovered per Trap | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* Spp. | *Sarcophaga* Spp. | Other Spp. | Total |
| 0–0.25 | 16 | 2.4 | 2.5 | 0.6[2] | 0.2[6] | 0.0 | 5.7 |
| 0.26–0.50 | 19 | 0.7 | 2.6 | 0.2[5] | 0.0 | 0.1[9] | 3.5 |
| 0.51–1.0 | 37 | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.9 |
| Total: 0–1.0 | 72 | 0.9 | 1.5 | 0.2 | 0.04 | 0.01 | 2.7 |
| 1.1–2.0 | 129 | 0.1 | 0.6 | 0.0 | 0.02[7] | 0.01[10] | 0.7 |
| 2.1–3.0 | 165 | 0.1 | 0.4 | 0.01[4] | 0.01[8] | 0.0 | 0.4 |
| 3.1–4.0 | 85 | 0.1 | 0.2 | 0.0 | 0.0 | 0.02[11] | 0.3 |
| 4.1–5.0 | 33 | 0.1 | 0.2 | 0.06[5] | 0.0 | 0.0 | 0.4 |
| 5.1–6.0 | 6 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 |
| 6.1–7.0 | 3 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.3 |
| 7.1–8.0 | 7 | 0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.6 |
| 8.1–9.0 | 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9.1–10.0 | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

[1] A total of 64 traps were used, but each trap was located at a different distance from the various release points and serves as several "traps" for the purpose of this table.
[2] 4 *sericata*, 4 *pallescens*, 1 *cluvia*, and 1 *caeruleiviridis*.
[3] 2 *sericata* and 1 *pallescens*.
[4] *P. pallescens*
[5] *P. sericata* and *P. pallescens*.
[6] *S. haemorrhoidalis, errabunda*, and *sueta*.
[7] *S. bullata* and *S. sueta*.
[8] *S. sueta*.
[9] *Syntheniomyia nudiseta*.
[10] *Phormia regina*.
[11] *Fannia pusio*.

more. Because of the increasing area included in each zone, however, the density of the flies would become steadily lower at increasing distances from the release points.

The maximum distances at which recoveries were made from release points were greater in the second test for all species. House flies and *Callitroga macellaria* were trapped 7.6 and 7.2 miles, respectively, from release points, *Phaenicia* 5.0 miles, *Sarcophaga* 2.1 miles, and *Fannia pusio* 3.5 miles (Table 5). The speed of movement of the flies was greater also in this second test. On the first day after release, house flies were recovered in several traps ranging from 0.25 up to 5.2 miles from the release point; *C. macellaria* were recovered up to 2.8 miles; and *Sarcophaga bullata*, 1.8 miles. On the second day after release,

**Table 6.—Percentage recovery of the total daily catch represented by marked flies at the respective release points in a dispersal test at Savannah, Georgia, July 1951.**

| No. | Release Point Location | *Musca domestica* | | | | | | | *Callitroga macellaria* | | | | | | | *Phaenicia* or *Sarcophaga* Spp. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No. of Days After Release | | | | | | | No. of Days After Release | | | | | | | No. Days After Release | | | | | | |
| | | 1 | 2 | 5 | 7 | 8 | 9 | 12 | 1 | 2 | 5 | 7 | 8 | 9 | 12 | 1 | 2 | 5 | 7 | 8 | 9 | 12 |
| I | High class residential | 25[1] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| II | Horse stable at junction of high, middle, and low class residential | 81 | 77 | 0 | 0 | 3.5 | 0 | 0 | 0.5[1] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| III | Farmers' market in business district | 0 | 2.3[1] | 0 | — | — | 0 | — | 0 | 0 | 0 | — | — | 0 | — | 0 | 0 | 0 | — | — | 0 | — |
| IV | Open area (cow pasture) | — | 0 | 0 | 0 | 0 | 0 | 0 | — | 0 | 0 | 0 | 0 | 0.2[1] | 0 | — | 0 | 0 | 0 | 1.6[2] | 0 | 0 |
| V | City dump | 1.6 | 0.9 | 0 | 0 | 0.1 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.7[2] | 2.0[2] | 0 | 0 | 0 | 0 | 0 |
| VI | Dairy | 19.1 | 5.8 | 0 | — | 0.8 | 0.5 | 0.04 | 0 | 0 | 0 | — | 0 | 0 | 0 | 0 | 0 | 0 | — | 0 | 0 | 0 |
| VII | Dairy | 23.4 | 17.3 | 6.8 | 3.0 | 2.3 | 3.1 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| VIII | Abattoir | 9.8 | 6.9 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5[1] | 0 | 0 | 0.1 | 0 | 0.05[1] | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] Based on single tagged specimen.
[2] *P. pallescens* and *P. sericata*.
[3] *S. sueta*.

**Table 7.—Distribution of recoveries of marked flies in the various types of urban areas in which traps were located in a dispersal test at Savannah, Georgia, July 1951.**

| Location of Traps | Number of Traps Operated | Number Recovered | | | | | | Average Number per Trap | | | | | | Per Cent Traps Catching Tagged Flies | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* Spp. | *Sarcophaga* Spp. | Other Spp. | Total All Species | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* Spp. | *Sarcophaga* Spp. | Other Spp. | Total All Species | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* Spp. | *Sarcophaga* Spp. | Other Spp. | All Species |
| High class residential | 8 | 1 | 7 | 0 | 0 | 0 | 8 | 0.1 | 0.9 | 0 | 0 | 0 | 1.0 | 13 | 50 | 0 | 0 | 0 | 63 |
| Middle class residential | 11 | 8 | 31 | 1 | 1 | 0 | 41 | 0.7 | 2.8 | 0.1 | 0.1 | 0 | 3.6 | 45 | 73 | 9 | 9 | 0 | 82 |
| Low class residential | 17 | 42 | 72 | 8 | 3 | 0 | 125 | 2.5 | 4.2 | 0.5 | 0.2 | 0 | 7.4 | 41 | 71 | 29 | 12 | 0 | 76 |
| Vacant | 13 | 11 | 115 | 2 | 1 | 1 | 130 | 0.9 | 8.8 | 0.2 | 0.1 | 0.1 | 10.0 | 31 | 92 | 15 | 8 | 8 | 92 |
| Industrial | 3 | 1 | 30 | 3 | 0 | 1 | 35 | 0.3 | 10.0 | 1.0 | 0 | 0.3 | 11.7 | 33 | 100 | 33 | 0 | 33 | 100 |
| Business | 2 | 3 | 2 | 0 | 0 | 0 | 5 | 1.5 | 1.0 | 0 | 0 | 0 | 2.5 | 100 | 100 | 0 | 0 | 0 | 100 |
| "Hot Spots" | 7 | 30 | 17 | 3 | 1 | 2 | 53 | 4.3 | 2.4 | 0.4 | 0.1 | 0.3 | 7.6 | 100 | 86 | 43 | 14 | 14 | 100 |

house flies and *C. macellaria* were recovered at the maximum distance for the test; *P. sericata*, 3.5 miles; and *P. pallescens*, 5.0 miles.

The data in table 6 indicate that the fly dispersal was rapid and continuous. In some instances only a single tagged fly was recovered at the release point. In general, the degree of recovery tended to vary directly with the attractivity of the site for flies, the more attractive points holding the marked flies longer. Even in these places, however, the movement of the flies outward was rapid, as evidenced by the rapid decline in the per cent of marked flies trapped in the fly populations at these sites. Beginning the eighth day after release, the traps were operated continuously at these sites, instead of the 1 hour daily. Even so, very few marked flies were trapped, and these almost entirely at the most attractive sites. At the same time, marked flies from all release points were still being taken in the outer traps.

A study of the dispersal patterns for house flies and for *Callitroga macellaria* indicated that wind directions seemed to have no detectable influence on the movement of the flies, which appeared to disperse at random, moving in all directions simultaneously. Daily dispersal patterns indicated that the flies frequently moved in opposite directions at the same time, passing each other in reaching the points at which they were trapped.

While the flies dispersed essentially at random, the pattern tended to skew toward those areas with the most attractants. This is clearly demonstrated by the data in table 7. The average number of marked flies taken per trap and the per cent of traps catching marked flies were higher in all other types of areas than in the better residential areas. Although the flies dispersed in all directions simultaneously, they tended to concentrate in those areas which were most attractive to them. These areas varied somewhat for the different types of flies. The poorer residential areas, the business district, and the so-called "hot spots" (which included horse stables, dairies, pig pens, and small garbage dumps) were the most attractive to house flies. While these areas were also attractive to blow flies, larger numbers of the latter were trapped in vacant and industrial areas. Except for the fact that they were partially occupied by buildings, the industrial areas were essentially "vacant" areas, in that they contained very few attractants. In fact, it is quite doubtful that either of these areas can be accurately described as being more "attractive" to blow flies than those areas preferred by the house flies. Their capture in great numbers in such areas is more apt to be simply evidence of the more migratory habits of the blow flies.

That heavy fly-producing sites outside a city will contribute substantially to the city's fly population was clearly demonstrated in the second test. Release points V–VIII, inclusive, represented such places, being a dairy and the garbage dump on one side of the city, and a dairy and an abattoir on the other side. House flies and blow flies from these sites moved into and completely across the city. The ability of

these common flies to move freely within a range of 4 miles or more in urban areas emphasizes the necessity for approaching municipal fly control on a city-wide basis. Since outlying foci of high fly production may also contribute substantial numbers of flies to the city proper, such places must be considered also. Since they are usually relatively few in number, it may often be desirable to include them in municipal fly control operations, especially if their fly production is high enough possibly to jeopardize the results of the control work within the city.

SUMMARY.—Employing as marking agents a combination of radioactive chemicals incorporated in their food and a variety of dyes dusted on them before release, dispersal habits of the common species of flies in urban areas were studied.

Dispersal was rapid, continuous, and in all directions, the flies frequently passing in opposite directions to reach the sites at which they were trapped.

The flies concentrated in greater numbers in those areas most attractive to them. Large numbers of *Callitroga macellaria* and some of all species were recovered in vacant areas considerably removed from major fly-breeding sources.

Heavy fly-producing sources near a city contribute substantially to the city's fly population. Flies from dairies, an abattoir, and the city garbage dump located outside the city moved into all parts of the city and completely across it.

The majority of the marked house flies and *Phaenicia* spp. recovered were trapped within one-half mile of release points in these tests, although approximately one-third of the recaptured house flies were trapped more than a mile away in one test. Most of the *Callitroga macellaria* recovered were trapped between 1 and 4 miles from release points. House flies were recovered as far away as 7.6 miles, *C. macellaria* 7.2 miles, *Phaenicia pallescens* 5.0 miles, *P. sericata* 3.5 miles, *Fannia pusio* 3.5 miles, and *Sarcophaga sueta* 2.1 miles.

If the recovery of marked flies per trap were adjusted to equalize the traps in each 1-mile zone on the basis of land area served by each trap, the results would indicate that large numbers of flies moved into each 1-mile zone up to 4 miles or more from the release points.

Municipal fly control should be approached on a city-wide basis, and in some instances it may be desirable to include in such control operations the most important of the immediately outlying foci of high fly production.

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# Fly Dispersal in a Rural Area near Savannah, Georgia

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The importance of insect dispersal in relation to control operations has long been recognized. The widespread use of DDT and other residual type insecticides for fly control in rural areas and the resultant development of fly resistance to these chemicals have emphasized the need for a more adequate knowledge of fly dispersal habits. In tests near Dallas, Texas, Bishopp & Laake (1921) developed now classical data on the flight ranges of several of the common species of flies. Powdered chalk of different colors and paint pigments were used as the marking agents in that work. More recently, Lindquist *et al.* (1951) conducted experiments in Oregon on the flight habits of *Musca domestica*, *Phormia regina* and *Phaenicia sericata*, using radioactive phosphorus as the method of tagging the test flies.

In both of these experiments, however, the test flies were released during the midportion of the day in open areas where there was little if any attractant material. The flies used in the releases were wild flies trapped in other locations or were laboratory-reared flies. The release of large numbers of flies at one point under these somewhat abnormal conditions may have affected their migratory tendencies. The studies reported here were conducted under conditions more closely approaching the natural environmental conditions of the test flies.

Procedure.—The area selected for these studies was a portion of Effingham County near Savannah, Ga. It is considered to be reasonably typical of the farming section of the Atlantic coastal plain of the southeastern United States. The premises are from $\frac{1}{10}$ mile to several miles apart, with extensive pine woodlands and low black gum and cypress swamplands frequently intervening. Structures comprising the farm units varied from isolated shacks to large dwellings with surrounding outbuildings housing livestock, chickens, and equipment.

The techniques for obtaining, marking, releasing, recovery, monitoring, and identification of the flies used in these two tests were the same as those employed by Quaterman *et al.* (1954) in their studies of fly dispersal in urban areas.

The property selected for the release point of the first test was a farm unit consisting of a large screened dwelling, three large barns housing livestock, several outbuildings containing equipment and farm supplies, and six large chicken houses containing approximately 10,000 chickens. This farm was considerably larger than the average unit, and was selected for its high fly population so early in the season. The marked flies were released at dusk on the evening of April 29, 1951. One recovery trap was placed at each farm unit within a 2-mile radius of the release point and at most of the premises within the 2- to 3-mile zone. Five traps were placed beyond the 3-mile zone. After the third day, three of the eight traps in the 1-mile zone and seven from other original points were removed and placed at new locations for various distances up to 8.25 miles (airline) from the release point. Traps were placed only on farm premises; none were placed in the open or wooded areas lying between the farm units. Molasses was used as bait on the first trapping day, but it failed to attract the flies effectively and the bait was changed to fish heads for the balance of the trapping period. Flies were trapped at several locations on the release point premises for approximately 1 hour on each of 7 out of 15 days following the release of the marked flies.

In the second dispersal test, five premises were selected as release points, located at distances ranging from $1\frac{3}{4}$ to $3\frac{3}{4}$ miles of each other. Four of these formed a rough rectangle, with the fifth located near the center. This fifth unit was the same one used as the release point in the first dispersal test. The other four were selected from premises at which high recoveries of tagged flies had been made in the first test, and represented more typical farm units. The tagged flies in this test were released on June 19, 1951.

Results.—In the first experiment, an estimated total of 13,500 *Musca domestica* and 600 others, mostly *Callitroga macellaria*, were tagged and released on April

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**Table 1.—Marked wild house flies in traps following release on a rural premises near Savannah, Georgia, April 30 to May 15, 1951.**

| Miles from Release Point | Number Traps Operated | Per Cent Traps Positive for Tagged Flies | No. Flies Trapped | | Per Cent | |
|---|---|---|---|---|---|---|
| | | | Total | Tagged | Trapped Flies Tagged | Tagged Flies Recovered |
| 0.15–1.0 | 8 | 100 | 16,244 | 845 | 5.2 | 6.26 |
| 1.1 –2.0 | 11 | 91 | 20,579 | 127 | 0.6 | 0.94 |
| 2.1 –3.0 | 25 | 68 | 4,697 | 73 | 1.6 | 0.54 |
| 3.1 –4.0 | 8 | 63 | 802 | 14 | 1.7 | 0.10 |
| 4.1 –5.0 | 3 | 33 | 864 | 1 | 0.1 | 0.01 |
| 5.1 –6.0 | 2 | 0 | 1,571 | 0 | 0 | 0 |
| 6.1 –7.0 | 2 | 0 | 2,234 | 0 | 0 | 0 |
| 7.1 –8.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8.1 –9.0 | 1 | 100 | 50 | 1 | 1.9 | 0.01 |
| Totals | 60 | 70 | 47,041 | 1,061 | 2.3 | 7.86 |

29. The failure of the molasses bait to attract the flies resulted in the complete loss of data at the release point for the day following release and for 2 days at the other trapping sites. The percentage of the total house flies trapped at the release point on the second and third days after release which were found to be tagged, was 24 and 24.9 per cent, respectively. Therefore, it was estimated that about 25 per cent of the total house fly population on the premises had been tagged. By the fifth day after release, only 4 per cent of the flies trapped on the release point premises were tagged flies. They had declined to 2.8 per cent by the eighth day, 0.5 per cent by the twelfth day, 0.2 per cent on the fifteenth day, and no marked flies were recovered on the sixteenth day when trapping was discontinued at all locations. On that last date, however, 11 traps at premises away from the release point contained marked flies, ranging up to 3 per cent of the total catch for that day in some traps.

It was not until the third day after the release that the outlying recovery traps operated effectively. On that day tagged flies were recovered in 11 traps ranging up to 3.7 airline miles and extending in all directions from the release point. Tagged flies were recovered in 20 traps on the fourth day and in 24 on the fifth day.

Daily dispersal maps were prepared and the direction of fly movement compared with the prevailing wind directions. There was no detectable effect of wind direction on the movement of the flies.

Almost 10 per cent of the total tagged house flies were recovered in traps. Approximately 8 per cent were taken in traps located on premises away from the release point, the most distant being 8.25 airline miles away—the farthest point at which a trap was placed. Had a suitable bait been used during the first 2 days after release, the percentage of tagged flies recovered probably would have been even greater.

One of the most striking features of this release was the indication that the premises selected as the release point contributed a high percentage of flies to the fly populations of surrounding premises. Tagged flies were collected in all of the traps operated in the area within 1 mile of the release point. Of the total house flies trapped in this 1-mile zone during the trapping period, 5.2 per cent were tagged flies (Table 1). When it is considered that an estimated 25 per cent of the flies present on the release point premises were originally tagged, it is reasonable to assume the tagged flies recovered in all traps represented approximately 25 per cent of the total flies migrating from the release point. On this basis of reasoning, over 20 per cent of the flies on the premises within 1 mile of the release point migrated from the release-point farm, 2.4 per cent in the 1- to 2-mile zone, 6.4 per cent in the 2- to 3-mile zone, and 6.8 per cent in the 3- to 4-mile zone. At some of the individual trapping sites, tagged flies on several occasions represented more than 15 per cent of the total house fly catch, suggesting that at least 50 per cent of the population may have migrated from the release point.

In surveying the area prior to selection of a site for the release point, it was noted that the house fly population was gen-

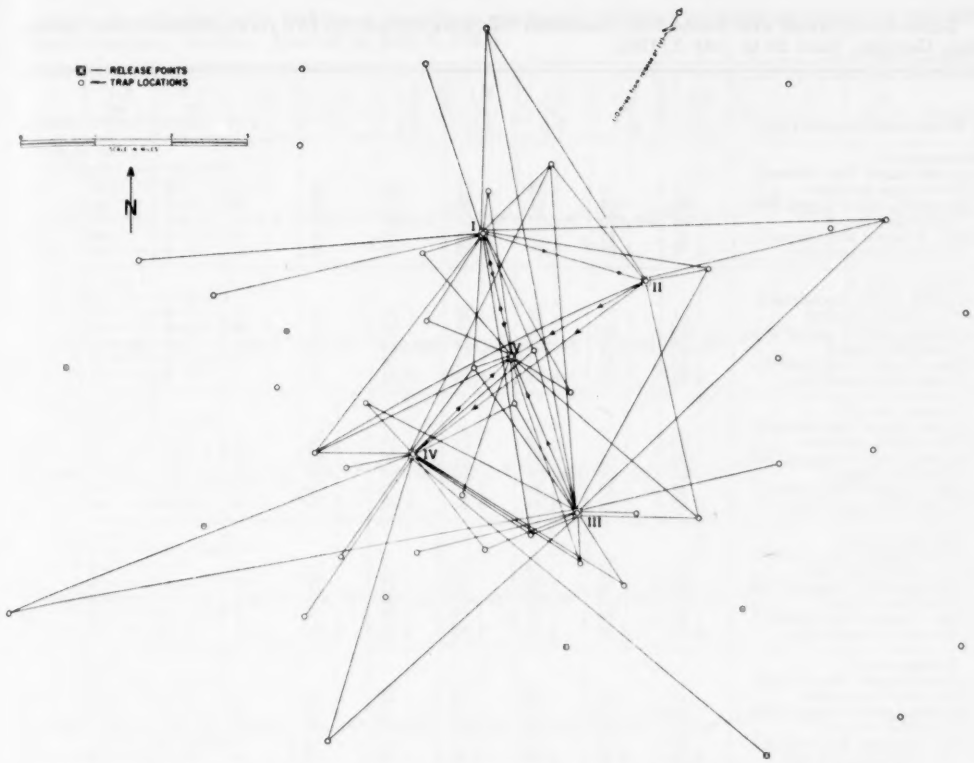


FIG. 1.—Simultaneous dispersal of wild *Musca domestica* from five release points in a typical rural area of southeast Georgia—June 20 to July 2, 1951.

erally low over most of the area, but was relatively high at the point of release and was increasing rapidly. Results of the dispersal test indicate rather strongly that a very high percentage of the flies over the large area covered by the traps originated at the release point, or were passing through there at the time test flies were trapped for marking.

There were only a few premises in the area with such high fly breeding potential. From the results of these studies, it would appear that effective fly control early in the season at these relatively few high fly producing premises might effect substantial fly reductions in a wide area.

In the second test, flies from the recovery traps were removed beginning at noon on June 20, following release of the marked flies after dark on the evening of June 19 at points I to IV, inclusive. Marked specimens were collected on this first day in 15 out of the 57 traps in operation, exclusive of those at the release points. Twelve of these 15 positive traps contained marked house flies, and ranged in distance up to 5 miles from the release points. Twenty-six traps contained marked flies on the second day, 25 on the third, and 24 for the week-end catch which was collected on the sixth day after release. On the seventh day only 11 traps contained marked flies, 12 on the eighth, 7 on the ninth, 5 on the tenth and only 2 for the second 3-day week end ending on the thirteenth day, which was the last day the traps were operated.

As in the first test, the flies moved in all directions simultaneously. Flies from three different release points were frequently recovered in the same trap on the same day. Centrally located traps often contained marked flies from two release points situated in opposite directions from the recovery traps in which they were caught. Figure 1 shows the composite dispersal pattern of the house flies in this second release test and is representative of the general pattern of dispersal of all species in both tests. The farthest distances at which marked flies were recovered were approximately $7\frac{3}{4}$ miles for

**Table 2.—Marked wild house flies recovered following release on five rural premises near Savannah, Georgia, June 20 to July 2, 1951.**

| Miles from Release Point | 0.1 to 1.0 | 1.1 to 2.0 | 2.1 to 3.0 | 3.1 to 4.0 | 4.1 to 5.0 | 5.1 to 6.0 | 6.1 to 7.0 | 7.1 to 8.0 | 8.1 to 10.0 | Totals |
|---|---|---|---|---|---|---|---|---|---|---|
| Release point I (1,500 tagged flies released) | | | | | | | | | | |
| No of traps operated | 3 | 4 | 12 | 9 | 9 | 9 | 4 | 5 | 2 | 57 |
| % traps positive-tagged flies | 100 | 100 | 42 | 44 | 0 | 0 | 0 | 0 | 0 | 28 |
| Total flies trapped | 6,546 | 163,335 | 50,304 | 88,406 | 41,899 | 45,034 | 4,218 | 37,283 | 3,995 | 440,980 |
| No. of tagged flies trapped | 11 | 13 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 34 |
| % recovery-tagged flies | 0.73 | 0.87 | 0.33 | 0.33 | 0 | 0 | 0 | 0 | 0 | 2.27 |
| Release point II (11,000 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 1 | 5 | 10 | 12 | 12 | 5 | 8 | 3 | 1 | 57 |
| % traps positive-tagged flies | 100 | 60 | 10 | 25 | 17 | 0 | 0 | 0 | 0 | 18 |
| Total flies trapped | 2,109 | 150,148 | 59,361 | 75,848 | 100,954 | 6,492 | 9,899 | 7,109 | 22,279 | 434,199 |
| No. of tagged flies trapped | 10 | 20 | 1 | 5 | 2 | 0 | 0 | 0 | 0 | 38 |
| % recovery-tagged flies | 0.09 | 0.18 | 0.01 | 0.05 | 0.02 | 0 | 0 | 0 | 0 | 0.35 |
| Release point III (5,400 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 3 | 7 | 8 | 12 | 10 | 5 | 5 | 4 | 3 | 57 |
| % traps positive-tagged flies | 100 | 57 | 63 | 17 | 20 | 20 | 20 | 25 | 0 | 33 |
| Total flies trapped | 35,201 | 20,836 | 151,204 | 111,358 | 47,802 | 18,095 | 22,912 | 28,736 | 2,715 | 438,859 |
| No. of tagged flies trapped | 47 | 12 | 10 | 2 | 2 | 1 | 2 | 1 | 0 | 77 |
| % recovery-tagged flies | 0.87 | 0.22 | 0.18 | 0.04 | 0.02 | 0.02 | 0.04 | 0.02 | 0 | 1.43 |
| Release point IV (7,700 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 3 | 11 | 9 | 8 | 9 | 4 | 7 | 4 | 2 | 57 |
| % traps positive-tagged flies | 67 | 64 | 33 | 25 | 11 | 25 | 14 | 0 | 0 | 30 |
| Total flies trapped | 17,299 | 168,919 | 97,220 | 22,801 | 61,896 | 29,538 | 21,479 | 17,776 | 2,033 | 438,961 |
| No. of tagged flies trapped | 25 | 34 | 11 | 2 | 1 | 1 | 1 | 0 | 0 | 75 |
| % recovery-tagged flies | 0.32 | 0.43 | 0.14 | 0.03 | 0.01 | 0.01 | 0.01 | 0 | 0 | 0.97 |
| Release point V (9,100 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 4 | 6 | 13 | 12 | 8 | 7 | 4 | 2 | 1 | 57 |
| % traps positive-tagged flies | 100 | 50 | 31 | 8 | 0 | 0 | 0 | 0 | 0 | 21 |
| Total flies trapped | 79,495 | 30,246 | 158,203 | 37,442 | 23,641 | 20,937 | 8,157 | 22,501 | 1,811 | 382,433 |
| No. of tagged flies trapped | 81 | 3 | 8 | 1 | 0 | 0 | 0 | 0 | 0 | 93 |
| % recovery-tagged flies | 0.89 | 0.03 | 0.09 | 0.01 | 0 | 0 | 0 | 0 | 0 | 1.02 |
| Totals for all release points | | | | | | | | | | |
| No. of traps operated | 14 | 33 | 52 | 53 | 48 | 30 | 28 | 18 | 9 | 285[1] |
| % traps positive-tagged flies | 93 | 64 | 35 | 23 | 10 | 7 | 7 | 6 | 0 | 26 |
| No. of tagged flies trapped | 174 | 82 | 35 | 15 | 5 | 2 | 3 | 1 | 0 | 317 |

[1] A total of only 57 traps was used, but since each trap served for each of the 5 release points simultaneously and was located so it was a different distance from each of the various release points, each trap was equivalent to 5 traps for the purpose of the total figures in this section of the table.

house flies in a west-southwesterly direction and approximately 10 miles for *Callitroga macellaria* in a northeasterly direction. Both were recovered in the first weekend trap catch collected on the sixth day after release and which included a 3-day catch of flies. In considering these long-distance catches, it should be kept in mind that out of the 57 recovery traps in operation, only from 3 to 7 of them were located more than 7 miles from the various release points.

Tables 2 and 3 present data on the recoveries of marked house flies and *Callitrogra macellaria* similar to that shown in table 1 for house flies in the first test. It will be noted from table 2 that the recovery of marked house flies in the second release was much lower than that of the first test. The contrast may be seen clearly by comparing the data in table 1 with that for release point V in table 2. The same premises was used as a release point in both tests. In the earlier study in May, almost 8 per cent of the marked flies were recovered away from the release point, as compared to only 1 per cent in the second test approximately 6 weeks later. The low recoveries of marked flies for the other 4 release points in June indicate that the recovery data for release point V were representative of conditions prevailing at that particular time.

There is no ready explanation for the low recovery of marked flies in the second test. The fly population was much greater throughout the test area in June than during early May. Based on the total number of house flies taken in the 60 recovery traps during 14 days of trapping (47,041) in May as compared to that taken in 57 traps during 13 trapping days in June (440,980), the total house fly population in the general test area was

**Table 3.—Marked wild *Callitroga macellaria* recovered following releases on five rural premises near Savannah, Georgia, June 20 to July 2, 1951.**

| MILES FROM RELEASE POINT | 0.1 TO 1.0 | 1.1 TO 2.0 | 2.1 TO 3.0 | 3.1 TO 4.0 | 4.1 TO 5.0 | 5.1 TO 6.0 | 6.1 TO 7.0 | 7.1 TO 8.0 | 8.1 TO 10.0 | TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|
| Release point I (250 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 3 | 4 | 12 | 9 | 9 | 9 | 4 | 5 | 2 | 57 |
| % traps positive-tagged flies | 67 | 25 | 25 | 0 | 11 | 11 | 0 | 0 | 0 | 14 |
| Total flies trapped | 1,031 | 1,692 | 7,212 | 5,406 | 6,163 | 5,221 | 2,977 | 9,848 | 2,538 | 42,088 |
| No. of tagged flies trapped | 2 | 1 | 4 | 0 | 1 | 1 | 0 | 0 | 0 | 9 |
| % recovery-tagged flies | 0.80 | 0.40 | 1.60 | 0 | 0.40 | 0.40 | 0 | 0 | 0 | 3.60 |
| Release point II (75 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 1 | 5 | 10 | 12 | 12 | 5 | 8 | 3 | 1 | 57 |
| % traps positive-tagged flies | 0 | 0 | 10 | 8 | 8 | 0 | 0 | 0 | 0 | 5 |
| Total flies trapped | 287 | 1,735 | 4,874 | 7,489 | 7,899 | 3,412 | 10,671 | 4,448 | 1,561 | 42,376 |
| No. of tagged flies trapped | 0 | 0 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 5 |
| % recovery-tagged flies | 0 | 0 | 4.0 | 1.33 | 1.33 | 0 | 0 | 0 | 0 | 6.67 |
| Release point III (50 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 3 | 7 | 8 | 12 | 10 | 5 | 5 | 4 | 3 | 57 |
| % traps positive-tagged flies | 67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| Total flies trapped | 3,757 | 3,544 | 2,952 | 9,029 | 11,437 | 4,941 | 1,925 | 3,536 | 1,087 | 42,218 |
| No. of tagged flies trapped | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| % recovery-tagged flies | 6.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.00 |
| Release point IV (1,000 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 3 | 11 | 9 | 8 | 9 | 4 | 7 | 4 | 2 | 57 |
| % traps positive-tagged flies | 100 | 64 | 67 | 50 | 11 | 25 | 0 | 0 | 50 | 40 |
| Total flies trapped | 1,335 | 6,867 | 5,918 | 6,998 | 8,696 | 2,196 | 5,362 | 3,758 | 785 | 41,915 |
| No. of tagged flies trapped | 24 | 22 | 12 | 5 | 2 | 1 | 0 | 0 | 1 | 67 |
| % recovery-tagged flies | 2.40 | 2.20 | 1.20 | 0.50 | 0.20 | 0.10 | 0 | 0 | 0.10 | 6.70 |
| Release point V (100 tagged flies released) | | | | | | | | | | |
| No. of traps operated | 4 | 6 | 13 | 12 | 8 | 7 | 4 | 2 | 1 | 57 |
| % traps positive-tagged flies | 25 | 17 | 15 | 18 | 0 | 0 | 0 | 0 | 0 | 11 |
| Total flies trapped | 1,687 | 2,047 | 9,313 | 7,802 | 4,257 | 8,874 | 5,600 | 1,680 | 666 | 41,926 |
| No. of tagged flies trapped | 1 | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 7 |
| % recovery-tagged flies | 1.00 | 1.00 | 3.00 | 2.00 | 0 | 0 | 0 | 0 | 0 | 7.00 |
| Totals for all release points | | | | | | | | | | |
| No. of traps operated | 14 | 33 | 52 | 53 | 48 | 30 | 28 | 18 | 9 | 285[1] |
| % traps positive-tagged flies | 57 | 27 | 23 | 13 | 6 | 7 | 0 | 0 | 11 | 15 |
| No. of tagged flies trapped | 30 | 24 | 22 | 8 | 4 | 2 | 0 | 0 | 1 | 91 |

[1] A total of only 57 traps was used, but since each trap served for each of the 5 release points simultaneously and was located so it was a different distance from each of the various release points, each trap was equivalent to 5 traps for the purpose of the total figures in this section of the table.

approximately 10 times greater during the second test period. The prevailing temperatures were also considerably higher during the second test, and the recovery traps were somewhat more dispersed.

From the data in tables 2 and 3, it will be noted that most of the marked house flies and *Callitroga macellaria* which were recovered were trapped within 3 miles of the respective release points. From these tables it may be seen that the dispersal patterns of house flies and *C. macellaria* were quite similar. However, it has been generally considered that *C. macellaria* are more migratory in their habits than house flies, and the higher rate of recoveries of the marked *C. macellaria* tends to substantiate that belief. If the numbers of *C. macellaria* released in the tests had been more comparable to the numbers of house flies, the greater migratory habits of the former may have been more clearly demonstrated.

In analyzing the recovery data, consideration must be given to the fact that the areas within 1 mile of the release points were, in general, more adequately trapped than the more distant zones. The land area per trap in operation increased greatly in each succeeding 1-mile zone around the release points. Consequently, the fact that most of the marked flies were recovered within the first 1-mile zone around the release points does not necessarily mean that most of the tagged flies remained within 1 mile of the release points. If the average number of marked flies recovered per trap in the respective 1-mile zones were multiplied by a correction factor to equalize all traps on the basis of land area served, the results would indicate that most of the tagged flies moved out beyond the 1-mile zone.

**Table 4.—Wild flies recovered[1] in traps following releases on five rural premises near Savannah, Georgia, June 20 to July 2, 1951.**

| RELEASE POINT | *Musca domestica* | *Callitroga macellaria* | *Phaenicia* SPP. | *Sarcophaga* SPP. | MISC. SPECIES |
|---|---|---|---|---|---|
| I | 1,500 (2.3) | 250 (3.6) | 30 (7)[2] | 30 (0) | 10 (20)[3] |
| II | 11,000 (0.4) | 75 (6.7) | 15 (0) | 30 (0) | 15 (20) |
| III | 5,400 (1.4) | 50 (6.0) | 35 (6)[4] | 70 (0) | 10 (0) |
| IV | 7,700 (1.0) | 1,000 (6.7) | 100 (0) | 200 (1.5)[5] | 100 (0) |
| V | 9,100 (1.0) | 100 (7.0) | 5 (0) | 20 (0) | 10 (0) |
| Totals | 34,700 (0.9) | 1,475 (6.2) | 185 (2.2) | 350 (0.9) | 145 (1.4) |

[1] Per cent recovered given in parentheses.
[2] One *Phaenicia sericata* recovered 2.25 miles from release point and one *P. caeruleiviridis* recovered 0.8 mile, both on the second day after release.
[3] One *Ophyra leucostoma* recovered 2.8 miles from release point on first day after release, and one *Muscina stabulans* 0.8 mile on the second day after release.
[4] Two *P. sericata* recovered 0.75 and 1.2 miles from release point, respectively, both on the second day after release.
[5] One *Sarcophaga sueta* recovered 1.3 miles from release point in week-end catch including the 4th to 6th days after release; one *S. bullata* 0.8 mile on the 7th day; and one *S. sueta* 2.7 miles on the 8th day.

This was especially true for the blow flies. As the flies were dispersed over larger areas as the distance from the release points increased, the density of the marked flies naturally decreased.

Table 4 also shows the recoveries of other species of marked flies. These recoveries must be considered as isolated flight records, since the numbers involved were too small to be of any substantial significance.

The speed with which the marked flies tended to move away from the release points is indicated by the data in table 5, which also indicates the percentage of the total fly populations which were marked on each of the release point premises. The percentages of flies marked at the release points, as indicated by the trap catches on the day following the releases, were in general agreement with observations of the fly populations on the respective premises at the time the flies were originally trapped for marking. The population at release point I was quite low and, while the figure 94 per cent for the proportion of marked flies in the population on the premises the day after release may appear high, it is the opinion of the writers that it is not too greatly in error. The percentages at release points II, III, and IV were well correlated with the observed fly populations. The figure for release point V is considered a little low, although the size of the premises and the enormous fly population which it produced and sustained, made it impossible to obtain any accurate visual estimate of the fly population.

From table 5, it will be noted that in most instances the marked flies apparently moved out rapidly to other locations. Within a few days the majority of marked flies had moved on from the release points. This rapid movement was substantiated by the large number of positive collections the first 3 days following the releases. As in the first test, marked flies continued to be taken in the recovery trap away from the release points after they ceased to be taken in traps at the release point.

The speed with which the marked flies left the release points, and their dispersal

**Table 5.—Per cent of house fly population represented by tagged flies trapped at five release points in rural areas of southeast Georgia at indicated intervals following their release.**

| RELEASE POINT | TRAPPING PERIOD (1951) | DAYS AFTER RELEASE | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| I | June 20–July 2 | 94 | 20 | 10 | — | — | — | 2 | 0.8 | 1.4 | 0 | — | — | 0 | — | — |
| II | June 20–July 2 | 24 | 11 | 9 | — | — | 6 | 2 | 1 | 0.5 | 1 | — | — | 0 | — | — |
| III | June 20–July 2 | 14 | 5 | 6 | — | — | 1 | 1 | 0.5 | 0 | 0 | — | — | — | — | — |
| IV | June 20–July 2 | 56 | 82 | 25 | — | — | 7 | 8 | 1 | 3 | 20 | — | — | 1 | — | — |
| V[1] | June 22–July 2 | 4 | — | — | 8[2] | 10 | 0.1 | 0.3 | 0.2 | — | — | 0.1[2] | — | — | — | — |
| V | Apr. 30–May 15 | — | 24 | 25 | — | 4 | — | — | 3 | — | — | — | 0.5 | — | — | 0.20 |

[1] Trap operated full time at this point and only 1 hour per day at all other sites.
[2] Represents a 3-day catch accumulating over a week end.

patterns based on the marked flies recovered, indicate that a very large majority of house flies and *Callitroga macellaria*, and perhaps other common species of blow flies, are constantly moving about probably at random within an area 8 to 10 miles in diameter, with some individuals dispersing even more widely. Within this area there appears to be a constant interchange of fly populations, with larger numbers concentrating at locations having more favorable supplies of food and breeding materials. Most of the premises used in these tests provided ample food and breeding material for flies. The fact that they left such places in great numbers and were frequently recovered in less desirable situations clearly demonstrates that flies normally range over a relatively large area in a manner similar to that observed for many higher forms of animal life. That flies, as other forms of life, have a "living space" in which they live has always been recognized, but the results of these tests indicate that this "living space" for house flies, at least, is much larger in area than was previously supposed.

SUMMARY.—Dispersal tests were conducted in rural areas of southeast Georgia with natural populations of wild house flies and *Callitroga macellaria*, obtained by trapping adult flies on the rural premises used as the release points. They were marked with radioactive phosphorus by feeding them milk containing P-32. The marked flies were released on the same premises on which they originally had been caught. To minimize the effects of the temporary caging, the releases of the marked flies were made at dusk after it had become too dark for them to migrate.

In a test conducted the first part of May, only one release point was used. In a second test during the latter part of June, five release points were used simultaneously. Dyes were used in combination with P-32 to mark the test flies. House flies were recovered up to 5 miles from the release points in less than 24 hours after release. The range and pattern of flight of the house flies in these tests were quite similar to those of *Callitroga macellaria*, although the higher percentages of *C. macellaria* taken in the recovery traps tended to substantiate the general belief that it is the more migratory of the two species.

In both tests the flies apparently dispersed at random over an area 8 to 10 miles in diameter, with a few individuals being trapped up to 10 miles from the release point. Within the general dispersal area, the flies tended to congregate more at premises where food and breeding material were more favorable. The availability of these materials, however, did not prevent great numbers of flies from leaving any given location, indicating that movement over this relatively large area is a normal pattern of fly activity.

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# Experimental Epidemiology in Relation to Arthropod-borne Disease[1]

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The purpose of this paper is to indicate certain potentialities inherent in the application of the principles and methods of experimental epidemiology to basic problems of arthropod-borne disease. The aims of experimental epidemiology are to study, under controlled laboratory conditions, the factors which govern fluctuations in the behavior of mass disease. The present discussion is concerned with four main topics: (a) basic principles in experimental epidemiology; (b) applications of quantitative methods, with particular reference to determinations of vector efficiency; (c) experimental models in which one studies systems composed of populations of suitable vectors, of pathogens, and of susceptible animal hosts; and (d) the broader aspects of these experimental approaches.

EXPERIMENTAL EPIDEMIOLOGY.—*Basic Principles.*—In epidemiologic studies of human disease, the unit of observation is the human population or "herd" (Wilson & Miles 1946). Thus one's terms of reference are taken from the *group* and from the behavior of disease in this unit. The characteristics of a population do not correspond to the summation of the characteristics of each of its members. A population possesses an individuality of its own, just as a person has his own individuality. Herein lies a fundamental difference between the point of view of epidemiology and that of clinical medicine, where one is concerned mainly with the *individual.*

The factors governing mass disease are classed broadly as the causative agent, the human host, and the environment (Gordon 1952). Environmental influences are grouped according to physical, biological, and social (including cultural and economic) components. When viewed in this context, epidemiology is medical ecology (Burnet 1953), and the principle of multiple causation follows logically therefrom. Since the elements of field and laboratory ecology (Allee *et al.* 1949) are familiar to the well-rounded entomologist, it is necessary merely to indicate certain aspects of their application to problems of infectious disease in general and arthropod-borne diseases in particular.

The primary biological units of study are populations of pathogenic micro-organisms, populations of vectors, and populations of animal hosts. Each of these populations has its fundamental requirements of nutrition, shelter, reproduction, and dispersion, for perpetuation as a species.

A pathogenic micro-organism usually requires a host in which to multiply. Since no individual host is immortal, the population of pathogens within this host must somehow get access to another host of the same or of a different species. Circumstances may arise, however, in which suitable hosts are not available, or means of transmission are not effective in sufficient degree to satisfy the requirements of our pathogen. Consequently this organism must possess adaptations which enable it to survive adverse circumstances (Andrewes 1950).

Thus the familiar requirements of higher organisms are seen to be shared by pathogenic micro-organisms. In studying the ecology of an arthropod-borne disease, one is concerned with the ecologic niche occupied by each of the living things involved, and with the effects of environmental factors upon each, as well as their relationships with the communities of which each organism is a member. In other words, the epidemiology of an arthropod-borne disease is a problem in the synecology and autocology of pathogen, vector, and host. It is reasonable to suppose that a promising experimental approach to such problems lies in controlled laboratory investigations designed to test and extend the qualitative and quantitative relationships suggested by epidemiologic field observations.

PAID PAPER.

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APPLICATIONS.—A primary problem in experimental epidemiology is the choice and design of laboratory investigations so that they have some bearing upon natural phenomena. Studies which lack this quality may be of even greater basic importance in other fields, but they have an air of academic unreality in the context of experimental epidemiology. Feasibility of performance is another criterion of equal importance. This aspect involves biological and technical questions which concern the etiologic agent, the arthropod vector, and the experimental host.

Finally, since the study of inter-relationships is an important objective, a quantitative approach is essential. In the case of many arthropod-borne diseases, present knowledge is on a sound and often adequate qualitative basis. The problem is to develop and refine quantitative methods in microbiology and entomology which are suitable for measuring the interrelationship which it is proposed to study.

*Vector Efficiency.*—a. Definition and Determination: Vector efficiency, as defined with respect to transmission of plague by fleas (Wheeler & Douglas 1941, 1945), is an experimentally determined numerical value which represents the average number of transmissions effected by a given individual of a particular species of vector under precisely defined and controlled conditions. This average number of transmissions is the mean of what is theoretically a normal distribution of such averages. Since it is determined under controlled conditions of transmission to laboratory animals, one must exercise extreme caution in trying to apply the results to problems of transmission to human beings. Although this limitation is not serious from the standpoint of experimental epidemiology, its existence must be clearly recognized.

Applications of the concept of vector efficiency to experimental studies of plague (Wheeler & Douglas 1941, 1945; Burroughs 1947; Holdenried 1952) have shown that it is a useful and productive tool, particularly when one desires to evaluate quantitatively the role of various determining factors. Hence the concept merits detailed consideration.

A clear illustration of what is meant is provided by the hypothetical example of Wheeler & Douglas (1945), where vector efficiency is the numerical product of three experimentally determined potentials: infection potential, vector potential, and transmission potential. Their example is paraphrased as follows: (a) 100 arthropods of a given species are offered potentially infective meals and 80 acquire the infection (the presence of the pathogen can be demonstrated in each of these 80 individuals); the infection potential is 0.8. (b) Of these 80 infected arthropods, 40 become infective, i.e., they become potentially capable of transmitting the infection if the opportunity arises; the vector potential is 0.5. (c) Each of the 40 infective arthropods is offered numerous opportunities to transmit, until the last one has died, and the total number of transmissions effected is 80; the transmission potential is 2. The vector efficiency thus determined is $0.8 \times 0.5 \times 2 = 0.8$. Thus, under the conditions of the experiment, this arthropod effected a mean of 0.8 transmissions per individual. What are the biological and technical requirements which must be satisfied before each of these three potentials can be determined, by critical experiments, for a given combination of arthropod, pathogen, and susceptible host?

General biological and technical requirements for determination of vector efficiency include the following: (a) a dependable source of non-infected arthropods; (b) methods for experimental feeding which permit control of dosage; (c) a host species which the pathogen will infect and on which the arthropod will feed readily; and (d) reliable methods for detecting and counting the pathogen. These requirements are more easily stated than satisfied, a fact which soon becomes apparent to those who undertake this sort of work.

When the mode of egress of the pathogen from the arthropod is such that transmission ordinarily takes place only at the time of feeding (an act which can be observed), and when the vector is one which takes multiple feedings, it is theoretically possible to apply the concept of vector efficiency to the design of experiments. The above points are best illustrated by concrete examples. Given below is a self-explanatory summary of the current status of limiting factors in the feasibility of determining vector efficiency in those cases where it is theoretically applicable.

**Summary—Vector-pathogen combinations to which the concept of vector efficiency is theoretically applicable[1]**

| GROUP | CURRENT MAJOR LIMITING FACTORS IN EXPERIMENTAL DETERMINATION OF VECTOR EFFICIENCY |
|---|---|
| A | Apparently none, therefore determinations are feasible. |
| | 1. Fleas and *Pasteurella pestis* |
| | 2. Fleas and *Rickettsia mooseri* (See text) |
| | 3. Certain mosquitoes and virus of yellow fever |
| | 4. Tsetse flies and *Trypanosoma* spp. |
| | 5. *Ornithodoros* ticks and *Borrelia* spp. |
| | 6. Triatominae and *Trypanosoma* spp. |
| B | Suitable methods for rearing and maintaining the vector must be developed. |
| | 1. Culicine mosquitoes and virus of Japanese B encephalitis |
| | 2. *Allodermanyssus sanguineus* and *Rickettsia akari*. |
| C | Although the vector (certain species) can be reared, and experimental animals are susceptible to the pathogen, infection in these animals involves highly specialized problems which must be clarified before vector efficiency determinations are feasible. |
| | 1. *Phlebotomus* and *Bartonella bacilliformis* |
| | 2. *Phlebotomus* and *Leishmania* spp. |
| D | Man is the only known suitable host for the pathogen, |
| | (a) but suitable methods for rearing and maintaining the vector are available. |
| | 1. Anopheline mosquitoes and *Plasmodium* spp. |
| | 2. Various mosquitoes and *Wuchereria* spp. |
| | 3. Mosquitoes and virus of dengue fever[2] |
| | (b) and suitable methods for rearing and maintaining the vector must be developed. |
| | 1. *Simulium* spp. and *Onchocerca volvulus*[3] |
| | 2. *Chrysops* spp. and *Loa loa* |
| | 3. *Culicoides* spp. and *Mansonella ozzardi, Acanthocheilonema perstans*, and *Dipelatonema streptocerca*. |

[1] See text for discussion of vector-pathogen combinations which are not listed in the table. An unmodified concept of vector efficiency is theoretically applicable to blood-sucking arthropods which feed more than once, provided the mode of egress of the pathogen from the vector at the time of feeding is such that transmission potential can be determined by direct experiments.

[2] The intracerebral route of inoculation of mice as hosts for mouse-adapted strains of dengue virus (Sabin 1950), and the problem of the occurrence of viremia in the mouse, limit the suitability of these animals for transmission experiments.

[3] Although several species of large African wild mammals are hosts for a worm which is indistinguishable from the human pathogen, the feasibility of performing experiments with these animals is questionable.

In the case of fleas and murine typhus, if an infected flea is passing viable rickettsiae in its feces, it is presumably entitled to be called an infective insect. The ingestion of infected fleas might also serve to infect a susceptible host (Nicolle *et al.* 1933). Furthermore, owing to the viability of rickettsiae in flea feces (Blanc & Baltazard 1937), it is conceivable that susceptible hosts may become infected at a time when living fleas are not actually present. Hence an application of vector efficiency to fleas and murine typhus should be accompanied by further studies of the ecologic complex involved.

In the case of louse-borne epidemic typhus, infection potential depends upon the dosage of organisms ingested, and infectivity potential can be determined experimentally (Fuller 1953). Owing to the viability of the rickettsiae in louse feces (Chao 1949), as well as the indiscriminate defecatory habits of the human body louse (Buxton 1947), transmission is not limited to a definite, observable act on the part of the vector. Since transmission potential consequently cannot be measured, it follows that vector efficiency cannot be determined. In the case of louse-borne typhus, it would seem that host and environmental factors enhance or decrease transmission insofar as they affect: (a) the dynamics of the louse population, (b) the elaboration of rickettsiae by infected lice, and (c) the viability of rickettsiae in louse feces. Although quantitative studies of certain aspects of these phenomena (Buxton 1947, Fuller 1953, Chao 1949) have yielded pertinent information, an attempt to integrate this information serves only to re-emphasize the importance of human activities as they affect the obligatory human parasite, the human body louse. Hence an attempt to define or determine vector efficiency in this instance would seem to be unrealistic and unproductive.

In the case of body lice and relapsing fever, determinations of infection potential and vector potential might be of interest with respect to comparative studies of lice infected with strains which are usually tick-borne (Baltazard *et al.* 1947). In the natural transmission of louse-borne

strains, the spirochetes apparently get out of the louse only when the insect is crushed (Wenyon 1926). Hence an individual infective louse can effect only a single transmission (Buxton 1947). This limiting factor consequently determines that transmission potential cannot be greater than vector potential in this instance

In the case of pathogens which are transmitted by ixodid ticks or by trombiculid mites, determination of vector efficiency in the usual sense is complicated by three facts: (a) the vector ordinarily feeds only once in a given stage; (b) transstadial passage (i.e., larva to nymph, or nymph to adult) of the pathogen often occurs; and (c) transovarial passage often occurs. These generalizations apply to tick-borne rickettsioses of the spotted fever group, to tick-borne viruses such as those of Colorado tick fever and far eastern tick-borne encephalitis, to tick-borne tularemia, and to scrub typhus. In such instances, one desires experimental determinations of the percentages of trans-stadial and transovarial transmissions which occur, observations of transmission potentials for the single feeding of individuals of a given instar, and further studies of the longevity of rickettsiae (Parker 1948) and of *Bacterium tularense* (Parker 1933) in tick feces. These systems may actually be more suited to the type of experimental approach described in the following section. This remark may apply also to transmission of relapsing fever by *Ornithodoros* ticks, and to transmission of rickettsial pox by *Allodermanyssus sanguineus.*

b. Relation to Natural Phenomena: Transmission of a pathogen occurs if an infective vector makes adequate and effective contact with a susceptible host. Since vector efficiency is a major determinant of effective contact, one desires information concerning effects of host, agent and environmental factors upon vector efficiency of an actual arthropod population. Examples of important properties of the vector itself are: longevity, frequency of contact with man or other hosts, and number and frequency of feedings. These more obvious factors relate not only to the individual arthropod, but also to the arthropod population. Certain pertinent properties of the agent include: presence or absence of multiplication within the vector (Huff 1931), mode of egress from the vector, viability outside the vector, and any possibly harmful effects upon the vector.

Examples of the role of environmental factors in their direct and indirect effects upon vector efficiency are too numerous and diverse to be presented adequately. Classic examples of direct effects are provided by field and laboratory observations of plague and fleas (Meyer 1942). A very subtle indirect effect of an environmental factor upon vector efficiency has been described in the case of the transmission of African trypanosomiasis by tsetse flies (Burtt 1946). Flies which emerged from pupae which had been incubated at a certain temperature were significantly more efficient vectors than were flies hatched from pupae incubated at a lower temperature. Although the explanation is not apparent, the fact is established, and its importance to the epidemiology of trypanosomiasis is clear enough (Buxton 1948).

c. Summary: When technical difficulties have been surmounted, determination of vector efficiency can be applied to a variety of combinations of arthropod and pathogen, provided that transmission is associated with a definite and observable act of the vector. The value of the concept of vector efficiency has been demonstrated by the results of its application to quantitative experimental studies of plague and fleas. The use of this type of quantitative method enables comparative studies of two different species as vectors, as well as measurement of the effect of various important factors upon a particular species as a vector. Since the experiments can be so designed that the results have a direct bearing upon natural phenomena, such studies are properly regarded as quantitative experimental epidemiology.

EXPERIMENTAL MODELS OF THE SYSTEM COMPOSED OF ARTHROPOD-PATHOGEN-HOST.—Laboratory studies of populations of pathogenic organisms maintained together with populations of suitable animal hosts have provided basic quantitative information on the natural history of infectious disease. Some examples of this sort of investigation have been conveniently summarized (Wilson & Miles 1946). The principle is to select hosts of a convenient species, and a pathogen

which spreads among them. An epidemic is initiated in the test animal population, and the ensuing events are observed under the controlled conditions of the experiment. These conditions are such as to enable measurements of the effects of variables on the course of this artificial epidemic. Hence such studies are a sound approach to experimental epidemiology.

Application of analogous principles and methods to a specific arthorpod-borne disease is exemplified by the work of Bertram (1953). His observations concern mite transmission of a filarial worm among cotton rats. As Bertram points out, this is "the only filarial infection with which one can hope to set up and study in the laboratory one's own epidemic, or endemic state of a filarial infection with prospects of observing its evolution and characteristics in a not unreasonable period of time." Further advantages mentioned by Bertram are the ease of maintenance of cotton rat filariasis as a laboratory strain, and the ease of detecting and counting the worms during different stages of development in the mite and in the rat. Furthermore, the biology of the mite is sufficiently well known to enable the design of precise experiments. Bertram's observations of this model have shed light on some of the problems of human filariasis.

Since this type of approach is apparently fruitful, the possibility of its application to other problems of arthropod-borne disease merits consideration. Further discussion is devoted to three general topics: desirable characteristics of a suitable experimental model, examples of specific systems as experimental models, and a recapitulation. The present aim is to deal with principles rather than methodology.

*Characteristics of a Suitable Experimental Model.*—It was not by mere chance that Bertram's work was done with an almost ideal experimental model, for several years of critical thinking and painstaking observations preceded these particular studies. In attempting to evaluate other possible experimental models, attention must be given to properties of the pathogen, the vector, the animal host, and the immediate and general experimental environments.

a. General Considerations: Initial studies should be made of a model composed of populations of not more than one species each: pathogen, vector, and animal host. The operator must have adequate first-hand acquaintance with the characteristics of each component of the system before he puts them together as a model. It is well if the model is one which can be expected to give results in a reasonable period of time. Ease and simplicity of initiation and maintenance are desirable, and provision for introduction and control of variables is essential to the purpose of the study. It is not necessary that the system be one in which transmission is limited to a definite observable act on the part of the vector.

b. Pathogenic Agent: Desirable features include: ease of maintenance of the strain; a simple and reliable method for detecting and counting the micro-organism; simple methods for control of dosage; and minimal danger in the case of accidents. Dangers to immediate personnel are often reduced if a method for active immunization and a satisfactory therapeutic agent are available. From the standpoint of danger to the public, such experiments may be more easy to justify if they are performed only in a geographical locality where the vector and the agent have already been shown to occur under natural conditions. If the agent is one which survives in arthropod feces, or one which may result in a droplet-transmitted infection, the risk of air-borne infection is thereby increased. The advantages of using an animal pathogen which is non-pathogenic for man have been demonstrated (Bertram 1953), and further studies of analogous systems would undoubtedly be productive.

c. Vector: It is obvious that test-tube experiments must be performed with small numbers of non-infected and infected vectors, before one undertakes to study populations of infected arthropods. It is essential that a suitable method for continuous laboratory colonization of vectors free from infection be available. The ecologic life cycle and the biology of the vector must have been worked out. Since it is desirable to account for each individual in the arthropod population, ease of confinement and enumeration are important considerations. Speed and means of movement are also relevant. For example, crawling arthropods are more easily handled than those which hop, and these, in turn, more easily than flying insects.

One needs to know how exacting are the requirements of the vector population with respect to environmental factors. For example, *Ornithodoros* ticks are much more resistant to starvation and desiccation than are most other arthropods. Finally, although it is helpful if the presence of infection in a given individual can be demonstrated at a particular moment without harming the vector or altering the experiment, this may be very difficult to achieve in practice.

d. Animal host: It is essential that the experimental vertebrate be a suitable host for the agent and for the vector. This usually implies that the vertebrate is one in which the agent multiplies, and one on which the vector feeds. It is also essential that the response of the animal to infection can be detected and measured by techniques which give reliable and reproducible results. A host which destroys the vector, often eating it, is undesirable; for example, rodents may eat their ectoparasites and birds may eat mosquitoes. Experiments are facilitated if the vertebrate chosen is of relatively small size, easy to obtain, confine and maintain, and relatively inexpensive. In some instances one may wish to use a mammal which hibernates, or which breeds within the container in which the experiment is housed. All things considered, therefore, it is reasonable to think first of looking for experimental hosts among smaller mammal species, particularly rodents.

e. Environment: the container in which the experiment takes place and the design of a suitable laboratory are questions of methodology which are beyond our present scope. Several advantages are inherent in choosing a geographical area in which the presence of the vector and the pathogen have already been demonstrated. The matter of potential danger from accidental contamination of the environment by vector or pathogen deserves re-emphasis. It may be easier to perform the experiments in an environment where the natural occurrence of the component organisms indicates that local conditions are favorable. Furthermore, one may wish to obtain the components of the system from conveniently located natural sources.

*Specific Systems as Possible Experimental Models.*—Of the many conceivable systems composed of a human pathogen, an arthropod vector, and an animal host, six have been selected for discussion here. Each is conceived as consisting of *populations* of the three component species, and each is discussed in connection with a model in which a species of rodent serves as the experimental host.

a. Fleas and Plague: Examples of questions which might be put to this model are: How do ambient temperature and relative humidity affect the course of enzootic and epizootic plague? Given comparable conditions otherwise, what is observed during a flea-transmitted outbreak among captive wild rodents (e.g., ground squirrels), as opposed to an outbreak among captive commensal rats? Do we observe changes in properties (e.g., virulence) of *Pasteurella pestis* during the course of our artificial outbreak? What are the effects of absolute and relative population sizes of fleas and rodents upon the course of an outbreak? In what ways is the course of an outbreak modified by the various means used to initiate it? Is the presence of living infected fleas necessary to the maintenance of plague infection in the rodent population?

b. Fleas and Murine Typhus: Questions analogous to those concerning fleas and plague are applicable to experimental models of fleas, rodents, and murine typhus rickettsiae. One could also submit to the model a question which has arisen in the course of attempts to evaluate the effectiveness of murine typhus control measures: Is the proportion of rats, in which significant levels of specific antibody to murine typhus can be demonstrated, related to the size of the flea population?

c. Ixodid Ticks and Rocky Mountain Spotted Fever: Owing to the number of species of ticks found infected in nature (Cox 1952), the variety of susceptible animal hosts, the existence of rickettsial strains which differ in virulence, the recently demonstrated interference phenomenon (Price 1953), and the reversible changes in virulence under laboratory conditions (Price 1953a), this complex offers many basic questions which could be submitted to suitable experimental models. Furthermore, although the role of mammals as essential hosts for ticks is abundantly clear, their role as hosts for rickettsiae is poorly understood. Recent studies of the infection in cottontail rab-

bits and guinea pigs (Price 1953, 1953a, and 1953b) are basic to this question, and they encourage the use of these mammals in the type of experimental model visualized here. If a particular species of wild mammal is to be used in such a model, similar quantitative studies of the infection in this species must be made beforehand.

d. Ornithodoros Ticks and Relapsing Fever: This system offers worthwhile opportunities for study by reason of the following facts: the remarkable longevity of these ticks and their resistance to starvation and desiccation (Davis 1942); the multiple feedings of the nymphal and adult ticks (Davis 1942); the occurrence of trans-stadial and transovarial transmission of spirochetes, with quantitative relationships which depend upon the species of tick and spirochete concerned (Davis 1942a, 1948; Wheeler 1938); and the different modes of transmission dependent upon the presence of spirochetes in the tick's saliva, or in its coxal fluid, or in both (Burgdorfer 1951). Many species of *Ornithodoros* are easily maintained in the laboratory. Guinea pigs and white mice are suitable hosts for the ticks as well as for the spirochetes, and several of the species of smaller wild mammals and reptiles which serve as natural hosts for the ticks are adaptable to the conditions of laboratory maintenance.

e. Reduviid Bugs (Triatominae) and Trypanosomes: The suitability of this system as an experimental model is suggested by the following considerations: the number of species of Triatominae and the variety of small mammals which are suitable hosts for them as well as for the trypanosomes (Usinger 1944); the detailed available knowledge of the physiology of certain of the vector species (Wigglesworth 1947); the fact that the life cycle and biology of many of the vector species are known (Usinger 1944); the relative resistance of the vectors to starvation and desiccation, and the fact that they take multiple blood meals; the relatively simple techniques necessary for the rearing and maintenance of the vectors; and the fact that the micro-organisms are cultivable on relatively simple acellular media. Since the experimental model might include *Trypanosoma cruzi*, *T. rangeli*, or *T. ariariae*, the investigator has a wide variety of possible combinations from which to construct his model.

f. Trombiculid Mites and Scrub Typhus: The need for studies of transmission of *Rickettsia tsutsugamushi* among the members of experimental populations of small animal hosts has been pointed out (Bertram 1951). It is unlikely that an experimental approach will be wholly feasible until there is developed a consistently dependable method for maintaining colonies of the vector species under the conditions required for such experiments.

Examples of questions which await the development of a suitable model are: What is the role of intermurine vectors, apart from the species which attack man, in maintaining and spreading the rickettsiae? Are the wild animal species which are often listed as "reservoirs" actually essential to the perpetuation and continuity of the rickettsial population, or will the rickettsiae persist in the model when albino rats (or some other species) are substituted for wild rats? Is transovarial transmission quantitatively sufficient to maintain a self-perpetuating population of rickettsiae? Do infected vertebrate hosts act as donors of rickettsiae to non-infected mite larvae which feed upon them? These are but a few of the fascinating questions which should be explored when suitable methods have been developed.

g. Additional Models: The preceding examples have been selected for discussion from a much wider range of possibilities among arthropod-borne human pathogens. Many instructive models are to be found in the arthropod-borne micro-organisms which infect wild or domesticated animals. Theobald Smith's studies of cattle fever (Smith & Kilborne 1893) provide a classic example, and many others come to mind. For instance, the development of an apparent age-immunity to infection with *Trypanosoma lewisi* in albino rats is not shared by the natural commensal murine hosts of this flea-transmitted parasite. Studies of models composed of fleas, *T. lewisi*, and rats, albino or "domestic," should shed light on many basic biologic problems in the natural history of this protozoal infection.

*Recapitulation.*—An investigative tool of great potential value is an experimental model in which populations of a vector, of a pathogen, and of an animal host, are brought together in a controlled environ-

ment. When the system is studied as a whole, the dynamic inter-relationships among these populations and their environment are treated as a problem in ecology. When the operator does something to the system, he introduces a primary cause; the ensuing chain of events is observed and analyzed from the standpoint of multiple causation. If thorough and painstaking observations are made on a carefully controlled system, it should be possible to measure the effects of host, agent, and environmental factors upon the course of an arthropod-borne infection in the laboratory. This type of approach represents an application of epidemiologic principles and methods in basic studies of arthropod-borne disease.

BROADER ASPECTS OF THESE EXPERIMENTAL APPROACHES.—If a research program includes the foregoing types of approach, what are we justified in expecting of it? In other words, what is likely to emerge from the laboratory, other than one or more experimentalists bearing voluminous reports of investigations? Since the preceding remarks include examples of specific information to be gained, it is appropriate now to consider the broader implications of experimental epidemiology in relation to arthropod-borne disease.

These experimental approaches provide an opportunity for testing, under controlled conditions, observations made on a disease in its so-called natural state. Secondly, they would undoubtedly indicate relationships which had not been suspected previously, and such points would then be tested by further field observations. One might also expect such studies to give added meaning and direction to measures designed to control or prevent disease. Convincing demonstrations of these functions of experimental epidemiology are provided by the work on plague at the Hooper Foundation. (See Meyer 1952 for discussion and references.)

Finally, the laboratory often serves as a testing ground for hypotheses and theories. Relationships among the variables involved in the transmission of arthropod-borne disease have been developed with particular reference to human malaria (Macdonald 1950, 1950a, and 1952). These relationships have been expressed for malaria in a mathematical form which, with some modifications, might be applicable to other arthropod-borne disease complexes. It would be of great interest to test such ideas by the use of suitable experimental models. In short, these experimental approaches provide opportunities to study the biology of disease.

SUMMARY.—The aims of experimental epidemiology are to study, under controlled laboratory conditions, the factors which govern fluctuations in the behavior of mass disease. Since the very beginnings of medical entomology, the epidemiologic method has actually played an integral role in its development, for fruitful investigations of arthropod-borne disease have been based, consciously or unconsciously, on an ecologic approach. The result is the present wealth of information, mainly qualitative, which has served as a sound basis for developing and directing measures which control or prevent mass disease.

Potent factors influencing the effectiveness of a given arthropod species as a vector of human disease are concerned with the nature of the relationships between vector and pathogen, the population dynamics of the vector species, and the character of the relationships between populations of human beings and of vectors. Quantitative information on these points is essential to a clarification of the factors involved in multiple causation in a given situation. Laboratory studies of these questions must be integrated with field studies in order that greater meaning be given to both. The results of studies of fleas, plague and rodents demonstrate the value of the application of the epidemiologic method to a specific problem. Much of the qualitative information, and a fair amount of quantitative data, needed for similar studies of other arthropod-borne diseases, are currently available in many instances. It is strongly suggested that such types of investigation are needed, that they are feasible, and that they are likely to be fruitful.

It is concluded that when the principles and methods of experimental epidemiology, entomology, and microbiology, are integrated and aimed critically at specific problems of vector-borne disease, they offer investigative tools of broad potential applicability in basic and applied biological science.

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# Efficacy of Dieldrin and Aldrin in Area Control of the Chigger Vectors of Scrub Typhus

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The newer antibiotics such as chloramphenicol, aureomycin, and terramycin have revolutionized the therapy of scrub typhus, but the prevention of this disease is still an important military problem. As has been shown by Smadel and his colleagues (1949, 1950), there is no satisfactory vaccine for scrub typhus, and chemoprophylaxis is practicable only under very special circumstances. Immunization by means of combined living vaccine and chemoprophylaxis is also of limited value (Smadel *et al.* 1952). At the present time, therefore, control of the vector chiggers offers the most promising approach in prevention of this disease.

Repellents effective against chiggers when applied to the skin were developed during World War II, but although these were made available in generous supply, they were not used on a sufficiently wide scale, since it is very difficult to ensure effective and proper utilization of repellent by individual soldiers. Wearing clothing impregnated with chigger repellents is accepted as being an important means of preventing scrub typhus as indicated by McCulloch (1946) and the U.S. Army (1948), but definitive experiments to fully evaluate this method are lacking. A preventive program based wholly on repellent-treated clothing has inherent disadvantages in that clothing is frequently shed in the tropics and also because the vector mites may attach to the arms and legs without coming in contact with the clothing. There is, therefore, great need for chemicals which will satisfactorily kill the chiggers on the ground. This paper presents data which show that the insecticides aldrin and dieldrin offer a very effective and practical means of area control of the chigger vectors of scrub typhus.[3]

Many compounds have been tried for the control of chiggers on the ground. The recent development of powerful toxicants of low volatility which maintain their lethal qualities over a period of months has finally made such efforts successful. The toxicants mentioned by Ewing (1921, 1927) offered little more than temporary relief, and Smith & Gouck (1948) found that even DDT proved to be little better than sulfur against American chiggers. Bushland (1946), in attempting to control itch-type chiggers of the genus *Schöngastia* in the forest litter of New Guinea, reported that 5 per cent DDT dusts applied at the high rate of 320 pounds per acre were of litttle value. Smith & Gouck (1947) also ascertained that DDT was inadequate against American *Eutrombicula alfreddugesi* and *Acariscus masoni* and that sulfur at the rate of 65 pounds per acre also was ineffective. These workers, however, found that crude BHC, containing about 10 per cent gamma isomer and applied at the rate of 8 pounds per acre, provided adequate control against these American trombiculids for a period of 5 to 8 weeks, resulting in a 98 per cent reduction in the mite population. Sulfur dust at the exorbitant dosage of 100 pounds per acre also afforded good results for 29 days, and the chlorinated hydrocarbon chlordane at the rate of 4 pounds of active ingredient per acre was quite effective for 2 weeks. Linduska &

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Morton (1947) and Linduska *et al.* (1948) also noted that crude BHC satisfactorily controlled American chiggers on the ground for 30 days when applied at the rate of 6 pounds to 50 pounds per acre. McCulloch (1947) demonstrated that BHC at the equivalent rate of 1 to 1½ pounds of gamma isomer per acre was effective for 2 weeks against Australian scrub-itch chiggers. On the basis of the work by Linduska, *et al.* and by McCulloch against pest species of chiggers, Audy (1949) recommended the use of gammexane (lindane) for the control of the chigger vectors of scrub typhus. Unpublished experiments by Traub and Frick in 1948 and 1949[4] in Malaya showed that dieldrin, aldrin, chlordane, toxaphene and lindane were very promising in the trol of *Trombicula akamushi* and *Trombicula deliensis*, the chigger vectors of scrub typhus. Dieldrin and aldrin seemed to be superior to lindane, toxaphene and chlordane in these preliminary tests. Unsettled conditions and bandit and terrorist activity unfortunately made it impossible to determine the duration of the residual effect of these insecticides at that time. The studies were resumed only in 1953, when a joint team of the U.S. Army Medical Research Unit (Malaya) and the Colonial Office Medical Research Unit, both headquartered at Kuala Lumpur, found suitable terrain infested with *Trombicula deliensis* at Ranau, elevation 1500 feet, at the base of Mt. Kinabalu in North Borneo, and conducted the experiments herein reported.

MATERIALS AND METHODS.—In order to evaluate the efficacy of the acaricides employed, it was necessary to find a practicable means for estimating the chigger population before and after the application of the toxicants. The abundance of the trombiculid vectors of scrub typhus in subtropical areas is not readily determinable by techniques which have been successful elsewhere for other chiggers. The method of counting the numbers of chiggers on boots of volunteers utilized in New Guinea against the itch-type chiggers of the genus *Schöngastia*, proved to be ineffective in Assam and Burma, as shown by Mackie *et al.* (1946). In Malaya, *Trombicula akamushi* and *T. deliensis* could be found on the shoes only under special circumstances and for a limited period of time, such as in exceptionally heavily infested terrain during the short period when the dew was drying on the grass (Philip *et al.* 1949). Placing small plates of glass, plastic or oilcloth on the ground is a highly effective means of determining the trombiculid population in sections of the southeastern United States. After 1 minute exposure as many as 50 to 150 chiggers could be found on the surface of the plate (Smith & Gouck 1947, Linduska *et al.* 1948). However, this technique likewise proved to be of little value in the Malaysian region against vector species, where even after 10 minutes' exposure we could never find more than one or two chiggers. The trap designed by Cockings (1948) also has been relatively ineffectual in Malaya (Philip *et al.* 1949). Methods used in Malaya by Traub & Frick (1950) were modified and used in these studies. This technique relies upon the numbers of chiggers in the ears of wild-caught rats and also upon the numbers of chiggers found in the ears of both laboratory white rats and wild rats following overnight exposure in an enclosed area. We believe that these methods provide an index of the actual chigger population in a given area.

Three plots were used in the experiments. Each was 300×280 feet in extent (1.9 acres) and was covered by extremely thick mixed growths of lalang, *Imperata cylindrica*, and other typical scrub vegetation. Two of these plots were separated by a 20-foot swath. The third was located one-tenth of a mile distant. *Rattus rattus* and *Rattus mülleri* naturally inhabiting this area were trapped throughout the course of the study and the chiggers attached to the ears were carefully counted. Rats were free to enter into the treated plots from outside the area, and undoubtedly some did so. For the purpose of the experiment, all chiggers found on rats caught within the plot were assumed to have been acquired therein, even though there undoubtedly was an influx of rodents into these plots from the untreated areas.

As a supplemental means of estimating chigger populations, and perhaps a more accurate method of assessing actual survival, a 50×50 foot section in the center of each plot was enclosed by means of

[4] Traub, R., and L. P. Frick. May 20, 1949. Interim Report on Miticides Tested in Malaya in 1949. Report to the Research and Development Board, Office of the Surgeon General, Department of the Army.

**Table 1.—Dieldrin and aldrin—Treatment of terrain in North Borneo, 1953—Numbers of chiggers on rats.**

| No. Days from Date of Spraying | Number of Rats | | | Numbers of Chiggers on Rats: Total Number | | | Numbers of Chiggers on Rats: Range | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fenced | | | Fenced | | | Fenced | |
| | Unfenced Rats | White Rats | Wild Rats | Unfenced Rats | White Rats | Wild Rats | Unfenced Rats | White Rats | Wild Rats |
| *Dieldrin Area* | | | | | | | | | |
| D minus 4–5 | 21 | 20 | 12 | 10,185 | 720 | 1310 | 240–650 | 27–45 | 80–200 |
| D minus 1–2 | 18 | 16 | 10 | 9,180 | 640 | 1200 | 220–690 | 30–51 | 90–200 |
| D plus 2–3 | 10 | 20 | 13 | 30 | 24 | 25 | 0–10 | 0–5 | 0–5 |
| D plus 4–6 | 9 | 16 | 13 | 72 | 32 | 48 | 0–12 | 0–5 | 0–10 |
| D plus 34–35 | 7 | 18 | 14 | 49 | 54 | 60 | 4–9 | 0–6 | 0–8 |
| D plus 37–38 | 7 | 16 | 2 | 70 | 42 | 70 | 7–21 | 0–6 | 0–9 |
| *Aldrin Area* | | | | | | | | | |
| D minus 4–5 | 16 | 16 | 12 | 11,200 | 1350 | 3800 | 400–1000 | 45–67 | 150–400 |
| D minus 1–2 | 13 | 18 | 10 | 10,480 | 1026 | 2250 | 500–900 | 45–70 | 150–425 |
| D plus 2–3 | 9 | 21 | 14 | 99 | 36 | 54 | 0–22 | 0–5 | 0–5 |
| D plus 4–6 | 10 | 13 | 7 | 50 | 39 | 35 | 0–15 | 0–6 | 0–9 |
| D plus 34–35 | 5 | 12 | 8 | 157 | 48 | 120 | 20–40 | 0–6 | 8–40 |
| D plus 37–38 | 7 | 18 | 11 | 212 | 58 | 220 | 22–48 | 0–5 | 8–28 |
| *Untreated Area* | | | | | | | | | |
| D minus 4–5 | 19 | 15 | 14 | 10,450 | 780 | 2072 | 450–650 | 39–57 | 95–200 |
| D minus 1–2 | 15 | 16 | 10 | 11,250 | 728 | 1600 | 600–1200 | 40–68 | 120–210 |
| D plus 2–3 | 10 | 24 | 18 | 8,500 | 1224 | 3420 | 750–1100 | 40–63 | 160–215 |
| D plus 4–6 | 10 | 20 | 12 | 8,200 | 960 | 2220 | 750–1200 | 38–65 | 155–200 |
| D plus 34–35 | 10 | 18 | 10 | 7,500 | 720 | 1700 | 650–900 | 30–55 | 150–220 |
| D plus 37–38 | 11 | 18 | 12 | 8,100 | 756 | 2280 | 550–950 | 25–56 | 130–250 |

three strands of electrified wire 3 inches apart, the lowest of which was about 1 inch from the ground. Immediately outside the electrified wires was a fence of chicken wire of 1-inch mesh, the bottom of which was buried in the ground to a depth of 8 inches and the ground scraped clear of vegetation for about 6 to 12 inches on each side of the fence to avoid short circuits. In essence the electrified fence was similar to that described in two papers by Ryckman *et al.* (1953) although simplified as much as possible by the use of bamboo posts instead of iron posts with braces. An ordinary farm-type electric fence charger powered by a six-volt dry-cell battery served to supply the current for one plot, while a single such charger served to electrify the fences of the two remaining plots. Within this electrified fence, laboratory white rats and wild-caught *Rattus rattus* and *Rattus mülleri* were released overnight and then trapped the next day by means of live-traps. From 12 to 20 white rats and 17 to 18 wild rats were released within each electrified plot during each trapping session. These wild rats had been kept in captivity a minimum of 1 week to allow the chiggers attached at the time of capture to detach naturally prior to exposure of the rats. After this overnight exposure within the fence, the chiggers acquired by the released rats were then counted as described below.

Rats which were alive at the time of capture were anesthetized by intraperitoneal inoculation of sodium nembutal at the rate of 40 milligrams per estimated kilogram of body weight in order to permit the counting of chiggers in their ears. Such rats were retained for subsequent exposure. Chiggers in the ears of dead rats and anesthetized animals were counted by means of a stereoscopic microscope and the chiggers were preserved in alcohol for subsequent identification.

After an estimate of the chigger population was obtained in the three areas, one was sprayed with aldrin[5], the second with

[5] The insecticides aldrin and dieldrin were obtained through the cooperation of the Julius Hyman & Company Division, Shell Chemical Corporation, Denver, Colorado. According to the specifications received from the Shell Chemical Corporation, the aldrin employed was a 23% emulsifiable concentrate containing approximately 23% Hexachloro-hexahydro-dimethanonaphthalene, 17% related compounds, 10% emulsifier, and 50% paraffinic solvent. The dieldrin formulation was in the form of a 19% emulsifiable concentrate containing 19% Hexachloro-Epoxy Octahydro Dimethano Naphthalene and related compounds, 8% emulsifier, and 73% paraffinic solvent.

**Table 2.—Aldrin-dieldrin treatment of terrain in Borneo. Average numbers of chiggers per rat (Chigger index).**

| No. of Days from Date of Spraying | Dieldrin Area | | | Aldrin Area | | | Untreated Area | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fenced | | | Fenced | | | Fenced | |
| | Unfenced Rats | White Rats | Wild Rats | Unfenced Rats | White Rats | Wild Rats | Unfenced Rats | White Rats | Wild Rats |
| D minus 4–5 | 485 | 36 | 110 | 700 | 55 | 250 | 550 | 52 | 148 |
| D minus 1–2 | 510 | 40 | 120 | 810 | 57 | 225 | 750 | 58 | 160 |
| D plus 2–3 | 3 | 1.2 | 1.9 | 11 | 1.7 | 3.3 | 850 | 51 | 190 |
| D plus 4–6 | 8 | 2.0 | 3.7 | 5 | 3.0 | 5.0 | 820 | 48 | 185 |
| D plus 34–35 | 7 | 3.0 | 4.3 | 31 | 4.0 | 15.0 | 750 | 40 | 170 |
| D plus 37–38 | 10 | 2.6 | 5.8 | 30 | 3.2 | 20.0 | 736 | 42 | 190 |

dieldrin[5], and the third was maintained as a control. The aldrin formulation contained 2 pounds of technical aldrin per gallon and the dieldrin formulation contained 1.5 pounds of the technical insecticide. The insecticides were applied as a fine mist by means of a pressure-type Banta spray gun at the rate of $2\frac{1}{4}$ pounds of insecticide (technical grade) per acre. Because of the high-pressure sprayer employed, the emulsifiable concentrates were applied in undiluted form. It was therefore necessary to use only a total of 2.2 gallons of the aldrin emulsifiable concentrate and 2.9 gallons of dieldrin emulsifiable concentrate to achieve the rate of $2\frac{1}{4}$ pounds per acre on our 1.9 acre plots.

At the times indicated in table 1, surveys were made in order to estimate the chigger population before and after the application of the insecticides.

Results.—As can be seen from table 1, chiggers were plentiful prior to the application of the insecticides. For example, in the area subsequently sprayed with dieldrin, the numbers of chiggers on 21 wild rats trapped in the unfenced portion of the plot ranged between 240 to 650 per rat.

In the control area chiggers were abundant throughout the entire test period, as shown in the table, and the numbers of chiggers on rats trapped in the unfenced area ranged between 450 to 1200 per rat. The average number of chiggers per rat (chigger index) for each of these areas is shown in table 2.

Approximately half of the chiggers found on these rats during the course of our studies were *Trombicula deliensis* Walch, a species known to be an effective vector of scrub typhus. Virtually all the remaining 50 per cent were *Trombicula* (*Eutrombicula*) *wichmanni* (Oudemans), a species heretofore believed to be essentially a parasite of birds.

Within 3 days after the spraying with insecticides, the chigger population on rats in the treated areas was tremendously reduced, as exemplified by an average of only three chiggers per rat on wild-caught rats in the unfenced section of the dieldrin plot and an average of 11 chiggers on wild-caught rats in the unfenced area of the aldrin plot (Table 2).

More than 5 weeks after application, the chiggger populations in the treated areas were still very low, but chiggers were still very abundant in the untreated plot. There were virtually 75 times as many chiggers on rats trapped in the untreated areas as in the dieldrin-treated plot, and nearly 25 times as many as in the aldrin-treated sector. The reduction in the chigger index in the treated areas is expressed percentagewise in table 3. Five weeks after application the average number of chiggers per unfenced wild rat in the dieldrin area was only 2 per cent of what it had been for the 5-day period prior to spraying.

There was no evidence that the insecticides caused damage to plants at any time.

Discussion.—It is emphasized that these insecticide studies were carried out in a region which is within 5 degrees of the equator and is hence characterized by the lush vegetation and heavy rains of the tropics. (Minimum of 100 inches per annum.) The vegetative cover was so thick that it was very difficult to see the soil and it seemed hard to believe that the insecticides would actually penetrate through this mat of vegetation to reach

**Table 3.—Reduction in numbers of chiggers[1] on rats after application of dieldrin and aldrin in North Borneo.**

| No. Days from Date of Spraying | Dieldrin Area | | | Aldrin Area | | | Untreated Area | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fenced | | | Fenced | | | Fenced | |
| | Unfenced Rats | White Rats | Wild Rats | Unfenced Rats | White Rats | Wild Rats | Unfenced Rats | White Rats | Wild Rats |
| D minus 1–5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| D plus 2–3 | 0.6 | 3 | 1.7 | 1.5 | 3 | 1.4 | 131 | 93 | 123 |
| D plus 4–6 | 1.6 | 5 | 3.2 | 0.6 | 5 | 2.1 | 126 | 87 | 120 |
| D plus 34–35 | 1.4 | 8 | 3.8 | 4 | 6 | 5.5 | 116 | 73 | 110 |
| D plus 37–38 | 2.0 | 7 | 5 | 4 | 5 | 8.5 | 113 | 76 | 123 |

[1] Expressed in percentages, with the average number of chiggers per rat before application considered 100 per cent.

the ground surface and control chiggers. It is also noteworthy that the dilution factor imposed by the tropical rainfall did not materially adversely affect the residual properties of the insecticides. During the first 3 weeks and the sixth week of the experiment it rained heavily. The intervening period was relatively dry for Borneo but there was some rainfall virtually every day, and the humidity was such that there was dew on the ground every morning and evening.

The full duration of the residual effect of dieldrin and aldrin has not been determined. There is evidence to indicate that these insecticides are effective for a minimum of 8 weeks. Thus, there was an average of 1.5 chiggers on each of nine white rats exposed within the electric fence at this time in the dieldrin area. In the aldrin area five such rats had an average of 4 chiggers each, whereas in the control area six white rats carried an average of 20. These figures are merely suggestive and have not been included in the above tables because of inadequate sampling due to a shortage of wild and white rats.

These experiments do not provide any direct information as to whether dieldrin and aldrin are toxic to the eggs or the nymphal and adult stages of chiggers, which normally inhabit the ground surface or superficial layers of the soil. However, since the species of chiggers encountered apparently breed throughout the year, the sustained low chigger populations after application of the acaricides indicate that there may be a toxic effect on these stages. The residual qualities of the toxicants minimize the importance of any possible lack of toxicity to non-larval stages.

Since rats were free to enter the unfenced portion of the experimental plots from outside the treated areas, it is probable that some of the chiggers which were found on the rats and accredited to the treated plots actually had been acquired elsewhere. It is therefore highly probable that the data from the unfenced treated plots reflect higher populations of chiggers than actually survived the treatments.

Inasmuch as dieldrin and aldrin wrought an appreciable decrease in the numbers of chiggers on rats for a minimum of 5 weeks after application, it is our opinion that the use of these insecticides offers a practicable means of disinfesting terrain. Of the two compounds, dieldrin is apparently the acaricide of choice. Some indication of the possible effect of the numbers of vector mites upon the infection rate of scrub typhus was observed by Traub & Frick in Malaya in 1950. Here it was shown that volunteers were more apt to acquire scrub typhus under conditions when the average number of *Trombicula akamushi* or *T. deliensis* per wild rat was above 375 and when white rats exposed in small pens overnight acquired between 19 and 55 chiggers each. Under such circumstances, 79 per cent of the volunteers sitting in the grass in infested terrain contracted scrub typhus. However, when the average number of vector mites per wild rat ranged between 12 and 304 and when exposed laboratory rats each acquired an average of 2.8 such chiggers, only 5 to 29 per cent of the volunteers acquired scrub typhus.

The reduction in the number of vector chiggers referred to by Traub and Frick was apparently effected by the onset of conditions of relative drought. They observed that in dry weather the numbers of

*Trombicula deliensis* and *T. akamushi* rapidly decreased, whereas non-vector chiggers, such as species of *Euschöngastia*, *Walchia* and *Gahrliepia* became absolutely and relatively more abundant. The incidence of naturally-contracted scrub typhus is also influenced by rainfall. In Malaya cases of scrub typhus were infrequent during or immediately following months with relatively little rainfall, whereas the majority of cases were contracted during the wet months.[6] There is a true dry season in Burma, and Sayers (1946) reported a very definite seasonal incidence of scrub typhus in Manipur and lower Burma. Audy *et al.* (1947), and Audy & Harrison (1951) showed that this seasonal incidence was correlated with the rise of the *T. deliensis* population during the rains and a marked decline during the dry season. A similar cycle for *T. deliensis* has been reported by Traub (1949) in Assam and North Burma, but the great numbers of susceptibles exposed during operations in the dry season obscured the seasonal pattern of the disease. For these reasons it is logical to postulate that the marked reduction in the numbers of vector mites brought about by the application of dieldrin and aldrin would result in a substantial decrease in the incidence of scrub typhus. The use of these insecticides is therefore recommended wherever numbers of susceptible individuals are to be exposed in endemic regions. The value of treating military campsites is obvious. Areas where troops are to be engaged in maneuvers should also be disinfested, particularly if such exercises are frequently followed by cases of scrub typhus. Thus, Audy *et al.* (1947) reported 756 cases occurring in units of "less than Brigade strength" following 4 days exposure in an infective focus. Outbreaks of scrub typhus have also been associated with clearing of scrub-covered land for agricultural purposes (Philip *et al.* 1949) and the application of dieldrin or aldrin is wholly practicable under such circumstances.

SUMMARY.—The insecticides dieldrin and aldrin provide a practical, efficient means for the control of the mite vectors of scrub typhus through the disinfestation of terrain. Approximately 50 per cent of the chiggers collected on *Rattus rattus* and *Ratttus mülleri* during the present studies in North Borneo were *Trombicula deliensis* Walch, an establsihed vector of scrub typhus, and virtually all the remainder were *Trombicula* (*Eutrombicula*) *wichmanni* (Oudemans). Dieldrin and aldrin, applied at the rate of $2\frac{1}{4}$ pounds per acre, effectively reduced the chigger population to the point where, within 3 days after application, an average of only three chiggers could be found in the ears of each wild rat in the dieldrin plot, while the chigger index in the aldrin plot was only 11. On the other hand, such wild-caught rats in the control area had an average of 850 chiggers. More than 5 weeks after application there were nearly 75 times as many chiggers on rats trapped in the untreated area as in the dieldrin-treated plot and almost 25 times as many as in the aldrin-treated sector. Of the two toxicants, dieldrin seems to be the acaricide of choice.

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[6] Since the rainfall pattern varies from year to year in any one district in Malaya, the fluctuations in incidence of this disease was not necessarily associated with any particular calendar months (Traub 1949, Traub & Frick 1949).

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# Response of Nut Grass to Soil Applications of Organic Insecticides[1]

J. G. WATTS[2]

The importance of nut grass, *Cyperus rotundus*, as a pest in cultivated fields at the Edisto Experiment Station has increased quite perceptibly in the past few years. There have been no changes in tillage and other farm practices which will satisfactorily explain the rather sudden increase in nut grass that has occurred in some fields. The most striking increases have been observed in fields which were planted to cotton and regularly treated for insect control for several years in succession. In a search for an explanation of this phenomenon the investigation has become aligned with a more comprehensive study of problems associated with the accumulation of organic insecticide residues in the soil. In the spring of 1952 striking variations in the nut grass population were noted among plots which had received different rates of organic insecticides. Although this species of sedge was generally present over the entire experimental area, certain plots were sharply delimited by an abrupt change in stand density.

PROCEDURE.—The treatments in the soil residue studies consisted of the following: (1) control, (2) BHC (3 per cent

[1] S. C. Agricultural Experiment Station Technical Contribution No. 210, presented at the meeting of the Cotton States Branch, Entomological Society of America, New Orleans, La., February 9–11, 1953.

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**Table 1.—Increase of nut grass in response to soil applications of several organic insecticides.**

| Insecticide | Pounds per Acre per Application | Five Applications, 1948–1952 Inclusive | | One Application, 1948 | |
|---|---|---|---|---|---|
| | | Total Pounds Technical per Acre | Mean Class Rating[1] | Total Pounds Technical per Acre | Mean Class Rating[1] |
| Control | — | — | 2.08 | — | 2.25 |
| BHC, 3% gamma[2] | 50 | 7.5 | 3.17 | 1.5 | 2.08 |
| | 250 | 37.5 | 4.17 | 7.5 | 2.25 |
| | 500 | 75.0 | 3.50 | 15.0 | 2.58 |
| Toxaphene, 20% | 50 | 50.0 | 2.09 | 10.0 | 1.84 |
| | 250 | 250.0 | 2.92 | 50.0 | 2.34 |
| | 500 | 500.0 | 3.17 | 100.0 | 2.09 |
| DDT, 5% | 50 | 12.0 | 2.17 | 2.5 | 2.00 |
| | 250 | 62.5 | 2.50 | 12.5 | 1.75 |
| | 500 | 125.0 | 3.00 | 25.0 | 2.25 |
| Chlordane, 10% | 50 | 25.0 | 2.17 | 2.5 | 2.00 |
| | 250 | 125.0 | 2.17 | 12.5 | 2.17 |
| | 500 | 250.0 | 2.50 | 25.0 | 2.00 |
| Parathion, 1% | 50 | 2.5 | 2.25 | 0.5 | 1.75 |
| | 250 | 12.5 | 2.00 | 2.5 | 2.00 |
| | 500 | 25.0 | 2.25 | 5.0 | 1.75 |
| L.S.D. (.05) | | | 0.26 | | N.S. |
| (.01) | | | 0.34 | | N.S. |

[1] Ratings based on number of plants per square foot according to the following: Class 1, 0 to 5; Class 2, 6 to 15; Class 3, 16 to 40; Class 4, 41 to 75; Class 5, 76 and above.
[2] From a low gamma (12 per cent) technical.

gamma), (3) 10 per cent chlordane, (4) 5 per cent DDT, (5) 1 per cent parathion, and (6) 20 per cent toxaphene. The insecticide concentrates were diluted with kaolin. A few days prior to planting these were broadcasted at rates of 50, 250 and 500 pounds per acre and disked into the soil. It is recognized that this procedure possibly resulted in more acute plant responses than if the same quantity of insecticides had been applied as in a normal insect control program.

This experiment consisted of two parts. In one series of plots single applications of the above mentioned formulations were made in 1948. In the other series annual applications were made for 5 consecutive years from 1948 to 1952 inclusive. The field arrangement of the experiment conformed to the randomized block design in which there were four replicates.

The response of nut grass to the different treatments was measured by fitting the average number of aerial shoots per square foot into a class rating scheme as follows: Class 1, 0 to 5 plants; Class 2, 6 to 15 plants; Class 3, 16 to 40 plants; Class 4, 51 to 75 plants; Class 5, 76 plants and above. Stand counts were taken at three predetermined locations in each plot.

RESULTS.—The data in table 1, column 4, show that where five annual applications of the insecticides were made, 8 of the 15 treatments incited an increase in the reproduction of nut grass. BHC was the most outstanding in this respect, and a significant increase in stand occurred at each of the three levels under test. In the case of both toxaphene and DDT a population increase occurred at the two higher levels while with chlordane such an increase occurred only at the highest level. Where only a single application was made at the beginning of the 5-year period, there was no significant difference in the nut grass population between the control and any of the treatments (Table 1, column 6). Parathion incited no increase in any instance.

No population counts were made of crab grass (*Digitaria* sp.) or other indigenous weeds, but there were no obvious differences in this respect between any of the plots except those receiving the two higher annual rates of BHC. In the latter plots there was an inverse relationship between the abundance of crab grass and that of nut grass. Weeds and grasses other than nut grass were virtually absent while the latter flourished.

DISCUSSION.—Grigsby (1951), Foster (1951) and Morrison, *et al.* (1948) reported limited herbicidal activity for some of the organic insecticides; Allen & Casida (1951) and Gould & Hamstead (1951) demonstrated that some of them were "stimulating" to the growth of certain plant species; also Morrison *et al.* (1948) reported that *Senecio vulgaris* L., Compositae, flourished on soil which had been treated with 27.5 pounds of gamma isomer of BHC, but suggested that this may have been due to lack of competition from other weeds; Chapman & Allen (1948), Cullinan (1949), and Allen & Casida (1951) make reference to the auxin-like activity of certain of the organic insecticides. However, a plant response of the particular type displayed by nut grass, i.e. increase in the rate of vegetative reproduction, apparently has not been reported previously.

It is of practical significance that five annual applications of BHC (3 per cent gamma) at 50 pounds per acre resulted in a significant increase in the nut grass population. This amount is well within the rate widely recommended and used for cotton insect control. Frequently twice this amount is used in a single sea-

son. Since annual applications of the two higher rates of toxaphene and DDT and the highest rate of chlordane increased nut grass populations, the possibility exists that continued use of these insecticides at recommended rates over a longer period of time may produce similar results. Although the data in columns 4 and 6 of table 1 can not be compared directly, there is an indication that successive annual applications of BHC (3 per cent gamma), rather than an equivalent amount in a single application, is of some consequence in bringing about this unusual response of nut grass. For example, when either 7.5 or 15.0 pounds of gamma from technical BHC were applied in a single application there was no significant increase in nut grass; however, when 7.5 pounds per acre was applied in five annual increments of 1.5 pounds each (50 pounds of 3 per cent gamma) there was a highly significant increase in nut grass.

The specific mechanism involved in inciting excessive nut grass reproduction by certain insecticides is not understood and an explanation of this phenomenon must await further investigation. However, certain pertinent observations have been made. It appears improbable that the control of some injurious insect could have accounted for the increase in nut grass, since the total insect damage of all sorts was so small. Also, the amount of insecticides required to produce the peak effect on nut grass is far above that normally required to control insects.

The possibility of nematode control was considered. Soil from the various plots was examined[3] for nematodes but resulted in no explanation for the difference in nut grass response. Also, parathion, which is said to have some nematocidal properties, did not affect the stand of nut grass.

No species, either wild or cultivated, except nut grass, responded favorably to increased amounts of the insecticides. In the case of higher rates of BHC all other species were strongly suppressed or eliminated, and at the 500 pound rate of BHC even nut grass was suppressed significantly when compared with the 250 pound rate. This observation suggests the possibility of an ecological interaction. Although this possibility can not be excluded, an appraisal of the growth manifestations of the various weeds, grasses and crops in the plots does not lend any particular support to this view.

It is conceivable that a hormonal or hormonal-like effect is brought about by the chlorinated insecticides or their products of decomposition. Present evidence indicates that such effects do not involve seed formation. Although nut grass produces well-formed spikelets, a very low percentage of the seeds are viable at this latitude. No viable seed were found in samples of seed head spikelets taken from each of the field plot treatments in the fall of 1952. Nut grass propagates from rhizomes, and apical dominance is exhibited in its chainlike root system of tubers. Possibly the insecticides have upset the auxins which control this apical dominance. Several chemicals are known to break apical dominance in other species; for example, ethylene chlorohydrin on gladiolus corms, and thiourea on potato tubers.

The abnormal increase in nut grass at the Edisto Experiment Station began to express itself some 3 or 4 years after the general adoption of the use of chlorinated hydrocarbons for cotton insect control. There is striking evidence that the two phenomena are related. If this is true, the continued use of these materials, particularly BHC, may further complicate the already difficult problem of weed control in cotton. This is especially true since nut grass is one of the most difficult of the common weeds to control either by cultivation or with herbicides.

SUMMARY.—A striking increase in nut grass abundance is reported which appears to be associated with accumulations in the soil of chlordane, DDT, toxaphene, and especially BHC, but not with parathion. The mechanism by which this "stimulation" has come about is not understood but certain pertinent observations have been made. It does not appear that insect or nematode control is involved. Although the possibility of an ecological interaction can not be excluded at this time, the growth manifestations of the various plant species involved do not lend any particular support to this view. Nut grass exhibits apical dominance in its chain-like root system of rhizomes and there is the possibility that the insecticides have interfered with the auxins which control this apical dominance.

[3] Dr. T. W. Graham, Plant Pathologist, U.S.D.A., Pee Dee Experiment Station, Florence, South Carolina, made the examinations for nematodes.

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# Bait Studies for Fly Control[1]

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Thompson *et al.* 1953 reported the successful use of lindane, TEPP and a combination of these two materials as toxicants in fly baits. Baits have been used with varying degrees of success in the past. Morrill, as early as 1914, reported on the use of formalin in milk and beer, and such baits were used rather extensively some years ago. Fly baits containing arsenic are in the trade and have had limited use for many years.

Since 1946 when DDT became available for commercial use, the Department of Entomology at the University of Maryland has maintained a program to study the relative value of different insecticides, especially the chlorinated hydrocarbons for fly control. By 1952 such materials as DDT, methoxychlor, chlordane, BHC, lindane and dieldrin which formerly had given excellent control were generally unsatisfactory. Flies were either resistant or showing resistance to each of them. Tests that year in which these materials along with CS-708 and two relatively new phosphorus base insecticides, malathion and NPD (tetra-*n*-propyl dithionopyrophosphate) were used; only the last three materials showed promise.

Because of the facts outlined the writers undertook a study to evaluate other toxicants in baits for fly control. A total of 27 chemicals were studied (Table 1). Sugar solutions poisoned with three phosphorus base materials; namely, malathion, Diazinon and a dialkyl phosphate received under the code name of Bayer's L 13/59 gave unusually satisfactory results in the laboratory and under field conditions.

METHODS AND PROCEDURES.—All baits were first tested in the laboratory. Those showing promise were then taken to the field for practical evaluation, where they were tested in a variety of situations such as dairy barns, animal pens, manure piles, garbage dumps, chicken houses and camp sites, as well as in back yards and on porches around homes. Basic field tests involved 51 barns, mostly dairy barns, and one entire town.

Cane sugar and black strap molasses were used to bait and attract the flies. Since under field conditions no practical differences in control were observed between the two materials, and molasses was was found to be objectionable in some cases due to stains and discolorations, cane sugar became the standard attractant.

The flies used in laboratory work were the 1951 NAIDM strain and were reared by the procedure described in the Peet-Grady Method. The flies tested were 2 or 3 days old, and selected at random without regard to sex. They were starved for 12 hours before being offered bait. The tests were made by introducing 30 flies into screened cages, size 10×12×13 inches. Each cage contained two petri plates, one of which contained a filter paper moistened with the attractant, the other with the attractant plus the insecti-

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**Table 1.—Effectiveness of 27 compounds used as toxicants for killing house flies in a 12.5 per cent sugar solution.**

| Insecticide | Laboratory: Per Cent Down or Dead 30 min. | 1 hr. | 24 hrs. | Field: Degree of Control After 24 hours |
|---|---|---|---|---|
| Aldrin 1% | 20 | 76 | 100 | — |
| BHC 1% | 43 | 76 | 100 | — |
| Bayer Compound L 13/59 .1% | 54.5 | 56.5 | 100 | Excellent |
| Chlordane 1% | 10 | 20 | 100 | — |
| Chlorobenzilate 1% | 0 | 0 | 60 | — |
| DDT 1% | 30 | 44 | 98 | Unsatisfactory |
| CS-708 1% | 13 | 20 | 80 | Fair |
| Diazinon 1% | 23 | 36 | 96 | Excellent |
| Dieldrin 1% | 20 | 66 | 100 | Unsatisfactory |
| Heptachlor 1% | 6 | 48 | 100 | Unsatisfactory |
| Lindane 1% | 3 | 6 | 100 | Unsatisfactory |
| Lethane 384 3% | 0 | 0 | 0 | — |
| Malathion 1% | 43 | 56 | 93 | Excellent |
| Metacide 1% | 23 | 23 | 100 | — |
| Methoxychlor 2% | 23 | 20 | 93 | Unsatisfactory |
| N.P.D. 1% | 36 | 40 | 90 | — |
| Parathion 1% | 13 | 13 | 90 | — |
| Strobane 1% | 10 | 36 | 96 | — |
| TEPP .5% | 53 | 56 | 100 | Excellent |
| Toxaphene 1% | 40 | 56 | 100 | Unsatisfactory |
| Borax (Saturated) | 0 | 0 | 33 | — |
| Boric Acid 0.63% | 3 | 3 | 50 | — |
| $CuSO_4$ 2% | 0 | 0 | 36 | — |
| Formalin 2% | 16 | 16 | 30 | — |
| Cryolite 1% | 0 | 0 | 0 | — |
| NaF 2.5% | 0 | 0 | 66 | — |
| Rotenone 1.3% | 0 | 0 | 50 | — |

cide being tested. By this method the flies had a choice between poisoned and non-poisoned food. Each test was replicated one or more times, and each chemical was tested on two or more occasions.

Under field conditions the baits were applied with either a sprinkling can or a compressed air sprayer adjusted to deliver a coarse spray. In several instances where large dumps were involved, or the area to be treated was extensive a power sprayer was used. The sprinkling can was used in barns with concrete floors. There the baits were applied to the floors. Where concrete floors were not available the baits were applied as a coarse spray to window ledges, door jambs, stanchion pipes, ceiling beams, and other such locations where flies usually congregate.

RESULTS.—Of the 27 chemicals under test (Table 1) only organic phosphates showed outstanding performance under field conditions. Because of their extremely poisonous nature parathion and Metacide were not used in animal barns, but the others, malathion, TEPP and two relatively new experimental products; namely, Diazinon and a water soluble dialkyl phosphate received under the code name of Bayer's L 13/59 were found to be excellent toxicants in fly baits. At the proper dosage level these materials seemed to be equally effective for eliminating flies from barns. Table 2 shows results from various concentrations of these materials for killing flies under laboratory conditions. Malathion, Diazinon and Bayer's L 13/59 were found to remain toxic in

**Table 2.—Effectiveness of some organic phosphate insecticides used as toxicants in house fly baits in the laboratory.**

| Insecticide | Per Cent Dosage | Per Cent Attractant | Per Cent Knockdown After Following Intervals: *10 Min.* | *30 Min.* | *1 Hr.* | *24 Hrs.* |
|---|---|---|---|---|---|---|
| Malathion | 1.5 | 12.5 sugar | 26 | 30 | 33 | 100 |
| 57% emulsion | 1 | 12.5 sugar | 33 | 43 | 56 | 93 |
| | .29 | 6 sugar | 33 | 56 | 70 | 100 |
| Wettable powder | .013 | 12.5 sugar | 16 | 30 | 33 | 83 |
| Diazinon | 1 | 12.5 sugar | 13 | 23 | 36 | 96 |
| 10% emulsion | 1 | 10 Dimalt | 30 | 33 | 40 | 100 |
| 10% emulsion | 2 | 12.5 sugar | 0 | 23 | 26 | 100 |
| | .29 | 6 sugar | 10 | 30 | 43 | 100 |
| Wettable powder | .013 | 12.5 sugar | 23 | 30 | 33 | 86 |
| Bayer Compound | 1 | 12.5 sugar | 14.5 | 36.5 | 53.0 | 100 |
| L 13/59 | .1 | 12.5 sugar | 49.5 | 54.5 | 56.5 | 100 |
| Technical Powder | .013 | 12.5 sugar | 46.5 | 54.5 | 63.0 | 98.5 |
| Water Soluble | .002 | 12.5 sugar | 0 | 0 | 0 | 60 |
| TEPP | .1 | 6 sugar | 50 | 60 | 66 | — |
| 40% liquid | .2 | 12.5 sugar | 30 | 36 | 43 | 96 |
| | .5 | 12.5 sugar | 26 | 53 | 56 | 100 |
| Metacide | 1 | 12.5 sugar | 20 | 23 | 23 | 100 |
| N.P.D. | 1 | 12.5 sugar | 0 | 36.6 | 40.0 | 90.3 |
| Parathion | 1 | 12.5 sugar | 6.6 | 13.3 | 13.3 | 90 |

prepared baits for several weeks and therefore would kill flies for considerable periods after application. In every place where baits prepared with the above materials were used excellent fly kills were obtained. TEPP, while an excellent fly killer, had a disadvantage in that it lost its killing qualities within 6 to 8 hours after being mixed with sugar and water. In some barns estimated counts showed from 50,000 to 70,000 dead or dying flies on the floor within the brief period of from 1 to 2 hours after application. Flies would begin to drop and die within 10 minutes after application and usually from 80 to 90 per cent of the flies in the barns would be dead in from 1 to 3 hours.

There was a great variation between laboratory and field results where the chlorinated hydrocarbons were used. A total of 11 of these insecticides were tested (Table 1) and all gave excellent kills on non-resistant flies under laboratory conditions. Six of these, DDT, dieldrin, heptachlor, lindane, methoxychlor and toxaphene were tested in barns and none gave effective control. The miscellaneous products tested such as borax, copper sulphate, formalin, cryolite, sodium fluoride, and rotenone were relatively ineffective at the dilutions they were used. A fair degree of control was obtained with CS-708, but the results were not comparable with those obtained with the organic phosphates.

MALATHION BAITS.—Because of availability and known information on the low order of toxicity of malathion to warm blooded animals, it was tested extensively for fly control. Baits were tested in which both the malathion and sugar content were varied, the malathion from ½ to 2 ounces of 57 per cent emulsion, and the sugar from ½ to 2 pounds in 1 gallon of water. All of these concentrations were effective for eliminating flies from barns when used daily or every second day. The length of time barns remained free of flies after the last bait application varied considerably regardless of the concentration of poison or sugar in the bait. However, the residual effectiveness of the baits was usually greater at the higher concentrations of malathion and sugar. The maximum period of protection obtained with the most concentrated bait was 2 weeks and the minimum period for the weakest formulation was 1 day. In several instances flies began to build up in from 2 to 5 days after an application of most concentrated bait. Other factors than concentration influenced the lasting qualities of the baits. So concentration should not be considered as the criterion. The daily treatments that the barns received, as well as the fly breeding conditions in and around them, appeared to have considerable influence on the lasting qualities of the bait. In floor treatments where the floors were scrubbed, hosed and limed daily there was no advantage from using the higher concentrations. On the other hand if the bait was applied to non-alkaline surfaces in relatively undisturbed situations considerable residual action was obtained from the use of the higher concentrations. A bait consisting of 2 ounces of 57 per cent miscible malathion, 2 pounds of sugar and 2 gallons of water properly applied with either a sprinkling can or a small compressed air sprayer was quite satisfactory. One application usually killed and kept a barn approximately free of flies for from 3 to 7 days. Because of the outstanding fly control being obtained in some of the test barns, word of the effectiveness of baits spread and malathion was used rather extensively by farmers in many communities in Maryland. Reports were received from 15 County Agents on the use of malathion baits. Every report showed excellent results. Several stated that their farmers felt it to be the most successful fly control product they had ever used.

The amount of bait required to treat a barn naturally varied with its size. But for the average 40 to 50-stall dairy barn from 2 to 3 gallons of bait applied to the concrete floor or to stanchion pipes, door jambs, window sills, and over head beams as a coarse spray with a compressed air sprayer was usually ample.

URBAN FLY CONTROL.—The garbage cans throughout the entire city of Easton, Maryland, a town with a population of approximately 5,000 were sprayed with a bait containing 1 gallon of 57 per cent malathion emulsion, 50 pounds of sugar and 100 gallons of water. This was accomplished by assigning one man with a compressed air sprayer to each garbage truck, and as the garbage cans were emptied he sprayed the cans, their lids, and the area immediately surrounding them. The value of this operation was very

evident in surveys which followed within 2 hours of the spraying operation. Great numbers of dead house flies, blue and green bottle flies, as well as numerous black blow flies, *Phormia regina* (Meig.), could be found around the garbage pails. Fly counts in which the number of dead and living flies found in the immediate vicinity of the garbage cans indicated that from 90 to 95 per cent of the flies had been killed. In an effort to determine the value of this bait on the total fly population in the town over a 10-day period, fly populations were studied before and after treatment by the methods described by Schoof, (1951), and duplicated by Burkhardt (1953). Fly counts were made with a modified Scudder grill. On the basis of grill counts made before and after treatment, the fly population during the 10-day period was reduced 50 per cent.

SUMMARY.—Twenty seven chemicals were studied and evaluated for possible use in baits for fly control. Three phosphorus base chemicals; namely, malathion, Diazinon and Bayer's L 13/59 showed outstanding promise when used in sugar solutions.

Because of its low toxicity to warm blooded animals, baits prepared with malathion were tested extensively in a variety of situations. These baits were found to be efficient for controlling flies in barns when applied to either the concrete floors with a sprinkling can or to the window ledges, door jambs, stanchion pipes and overhead beams as a coarse spray. Malathion baits also showed promise in urban fly control.

Baits prepared with chlorinated hydrocarbons as the poisoning agent were effective for killing non-resistant flies under laboratory conditions, but were unsatisfactory under field conditions. Baits poisoned with CS-708 gave a fair degree of control under field conditions, but the results were not comparable with those obtained with organic phosphates. The several miscellaneous products such as borax, copper sulphate, formalin, sodium fluoride and rotenone which were tested were relatively ineffective.

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# Control of *Myobia musculinus* (Schrank) and *Myocoptes musculinus* (Koch) on Laboratory Mice[1]

A. H. Madden, Albert H. Tozloski, and Harvey L. Sweetman

The trombidiform mite, *Myobia musculinus* (Schrank,), and the sarcoptiform mite, *Myocoptes musculinus* (Koch), are common parasites of laboratory mice. Both are very minute (approximately 0.20–0.40 mm. in length) but vary in general appearance, *Myobia* being elongate in shape with the front legs modified for clasping the hairs of the host, while *Myocoptes* is somewhat broader and shorter with lege III and IV modified as hair claspers. Although widely separated taxonomically, these mites are very similar in habits. Apparently neither form is a blood-sucker, each reportedly feeding upon oily secretions in the hair-follicles, though this type of feeding is a controversial point with respect to *Myobia* (Ewing 1938, Baker & Wharton 1952, Grant 1942). The constant irritation caused by a large number of these pests undoubtedly has a marked debilitating effect upon the animal. Furthermore, it has been stated by Snell (1941), that mice infested with *Myobia* sometimes mutilate themselves so severely by scratching that they must be discarded. While the presence of a limited infestation can be determined only by a microscopic examination of the animals, more heavily infested individuals may be detected readily by their emaciated condition and the slightly mangy, lusterless appearance of the coat.

During the greater part of 1952, a study was conducted on the control of these mites on a colony of mice. An attempt was made to find an effective and feasible treatment which could be applied without increasing materially the routine work connected with the maintenance of the colony. Preliminary tests with a number of materials, including *Ovotran*,[2] *Neotran*,[3] Aramite, DDT, and lindane, indicated that lindane was the most promising. Work was continued to determine the effectiveness of lindane and to test a limited number of potential compounds not included previously. While the tests were directed against a mixed population of both mites, they will be treated as a single form since no appreciable difference in the results was observed.

Methods.—The hosts used in these tests were practically all C3H strain mice. This large agouti strain with rather course thick hair was found to be not only the most heavily infested but also the most tractable of the strains available. The mice were maintained in 43×26×20 cm. plexiglass cages with perforated metal covers. White pine shavings were used as bedding. These were changed and the cages cleaned twice weekly in accordance with the regular schedule in the colony.

Some treatments were made by applying a pinch of the material directly to the body of the animal and rubbing it thoroughly into the fur, but the majority of applications were made by either sprinkling lindane or chlordane over the fresh bedding before the mice were returned to the clean cage, or shaking the animals for a few seconds with a small quantity of sulphur in a closed container and then returning them to a clean cage.

Because of the minute size of the parasites, the large numbers involved (approximately 1,000 to 1,500 per heavily-infested animal), and the activity of the host during examination, evaluation of results was made partially on a qualitative rather than a quantitative basis. The degree of infestation was determined microscopically, prior to treatment, and at frequent intervals during the test. At the termination of each test the animals were sacrificed by cervical dislocation and kept for several hours until the mites migrated to the ends of the hairs. It was possible then to make an accurate count of the total number on the host. Since the approximate number of mites at the various levels of infestation (heavy, medium or light) had been established by counts made on dead, untreated animals, a close estimate of the percentage control based on the initial observation and the final count could be made in each test. In order to secure reliable samples, repeated tests of the same materials were made on small

[1] Contribution from the Department of Entomology, University of Massachusetts, Amherst.
[2] Trade name for *p*-chlorophenyl *p*-chlorobenzene-sulfonate.
[3] Trade name for bis(*p*-chlorophenoxy)methane.

numbers of animals in practically all instances. A number of untreated animals were maintained as controls in each group.

To determine the possible toxicity to the animals of the various materials, as indicated by loss in weight, treated and untreated animals were weighed at frequent intervals.

RESULTS.—Initial experiments with lindane were conducted with 0.5 per cent dust, but after the completion of two tests the concentration was increased to 1.0 per cent, since 0.5 per cent did not provide satisfactory control even with frequent retreatments. Lindane was tested both as a body and a bedding treatment. The length of the test periods varied from 18 to 84 days, with retreatments being made in most tests. In general, there was an abrupt drop in the mite population following each application, but usually an appreciable increase in numbers occurred in about 2 weeks. This indicates that lindane was not ovicidal and that the residual action was of short duration.

The percentage control obtained with the various materials and methods of application is summarized in table 1. Good control with lindane was obtained in most cases only by repeated applications. Applications to the bedding were slightly more effective than applications on the animals. One test with chlordane applied to the bedding gave results comparable to those obtained with lindane.

**Table 1.—Control of *Myobia musculinus* and *Myocoptes musculinus* on laboratory mice with various dusts and methods of application.**

| Insecticide | Per Cent Conc. | Grams Applied | Number of Mice | Number of Treatments | Per Cent Control |
|---|---|---|---|---|---|
| | | *Applied to Animals* | | | |
| Lindane | 0.5 | | 5 | 3 | 80 |
| Lindane | 0.5 & 1.0[1] | | 4 | 4 | 95 |
| Sulphur[2] | 100 | | 12[3] | 1 | 99+ |
| Sulphur | 100 | | 4 | 1 | 98 |
| Sulphur | 100 | | 2 | 1 | 97 |
| Sulphur | 100 | | 4 | 1 | 96 |
| Sulphur | 100 | | 2 | 1 | 95 |
| | | *Applied to Bedding* | | | |
| Lindane | 0.5 | 15 | 4 | 3 | 90 |
| Lindane | 0.5 & 1.0[4] | 30.5 | 4 | 7 | 94 |
| Lindane | 1.0 | 10 | 6 | 1 | 98 |
| Chlordane | 5.0 | 5 | 8 | 1 | 94 |

[1] First three treatments 0.5 per cent, fourth treatment 1.0 per cent.
[2] 325-mesh dusting sulphur.
[3] Five tests, 1 to 4 mice per test.
[4] First treatment 0.5 per cent, all others 1.0 per cent.

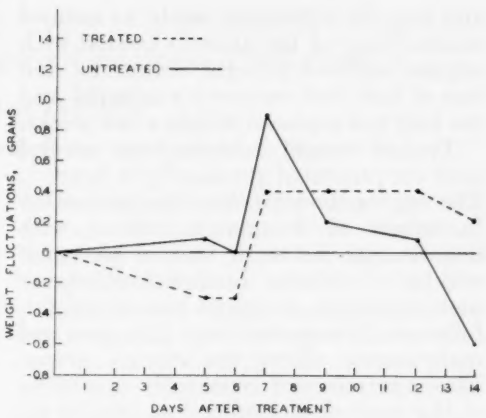


FIG. 1.—Average weight fluctuations over a two-week period of eight mice untreated and eight mice treated with Lindane.

Twenty-four hours after the application of sulphur, hundreds of dead mites were attached to the hairs of the treated animals, although many live mites were evident as late as 3 days after treatment. Most of the tests were terminated after 40 to 48 days. The high degree of control obtained with a single treatment indicates that sulphur is either effective against all stages of the mites or that residual action occurred. The sulphur usually was visible among the hairs of the host several days after application.

Many of the animals under test for mites were infested with a louse, *Polyplax serrata* (Burmeister), which is an important parasite of the laboratory mouse. Good control of this pest with sulphur occasionally resulted, but eradication was obtained by sprinkling 2 gms. of 5 per cent chlordane over the fresh bedding of a mouse cage. A number of tests showed that this material was compatible with sulphur, and that the combination was harmless to the mice.

None of the materials, as applied in these tests, were materially toxic to the animals. During the test period of about 11 months only three mice died, two in treated groups and one in a control group. The majority of the animals, being approximately 15 months old or older, were approaching the end of their normal life span. However, the death rate was comparable with that of the colony as a whole

and may be attributed solely to natural causes. Some of the animals treated with sulphur suffered a slight dermatitis and loss of hair, but recovery was rapid and the hair was replaced within a few weeks.

Typical weight records from several tests are presented graphically in figure 1. The curves show the average fluctuation in weight of 8 animals treated with lindane together with that of an equal number of controls. Lindane-treated animals exhibited an initial loss of weight, followed after several days by a gain and maintenance above the control group. This was recorded repeatedly regardless of the method of application. Similar results were obtained with sulphur. Subsequent increase in weight of all treated animals was presumed to reflect improved condition following control of the parasites.

DISCUSSION.—Caution must be used in interpreting the results since little is known regarding the biology of these mites. Either the lindane or chlordane bedding treatment or the sulphur body treatment was an effective means of controlling these mites on mice reared under conditions described above. Chemical control of external parasites of the laboratory mouse is necessarily restricted to the use of materials in dust or powder form since spraying is laborious and dipping involves the risk of the mice developing pneumonia (Snell 1941). While good control undoubtedly can be maintained by frequent applications of 1 per cent lindane or 5 per cent chlordane to the bedding, it should be kept in mind that these materials are toxic to warm-blooded animals, and therefore must be used with caution. Sulphur, on the contrary, is a relatively harmless material and the data indicate that good control can be achieved with applications at bi-monthly or even less frequent intervals. It is safe to use on animals as young as 2 weeks of age, thus permitting universal application in the case of a severe outbreak. Furthermore, the animals may be deloused simultaneously by the application of chlordane to the bedding.

Although some movement of mites from animal to animal occurs, the spread is mainly from a dead animal to the other occupants of a cage. Therefore, it is a good supplementary practice to remove and destroy all dead animals as frequently as possible. Since infestation tends to increase with the age of the animal it is not only good management but also a means of retarding increase of the mite population if over-age animals are eliminated.

SUMMARY.—*Myobia musculinus* (Schrank) and *Myocoptes musculinus* (Koch) are common parasites of laboratory mice. Tests against these mites were conducted on C3H strain animals. The majority of the materials tested were applied either to the bedding or to the animal by shaking them in a closed container with the chemical. Good control was obtained with frequent applications of 1.0 per cent lindane, but sulphur is considered to be superior from a practical standpoint, since, as a rule, one application is effective over a period of several weeks and the material is relatively harmless to the mice. Control of the louse, *Polyplax serrata* (Burmeister), an important parasite of the mouse, was obtained by applying 5 per cent chlordane to the bedding. Chlordane may be used in conjunction with the sulphur treatment. Control measures should be supplemented by frequent removal and destruction of dead mice, and by preventing the accumulation of over-age animals.

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# The Effect of Systox on Some Common Predators of the Cotton Aphid[1]

MOSTAFA KAMAL AHMED,[2] L. D. NEWSOM, R. B. EMERSON, and J. S. ROUSSEL

Little information is available concerning the effect of Systox on predaceous insects. Several species of predators are important in controlling such cotton pests as the cotton aphid, spider mites, bollworm and tobacco budworm. The work reported here summarizes a study of the effect of Systox upon some of these predators.

REVIEW OF LITERATURE.—Ripper *et al.* (1949) reported that no dead adults or larvae of *Coccinella septempunctata* and *Adaila bipunctata* were ever found in fields treated with the systemic phosphate schradan and that moribund aphids from sprayed plants were not toxic to adult coccinellids. They also noted that the larvae of *Syrphus* sp. were usually not killed by spray formulations in field trials and that pupae of *Aphidius* sp. survived a 5 per cent spray formulation with no apparent toxicity to the adults.

Ripper *et al.* (1951) stated that, "Schradan causes no, or, at worst, a low mortality of beneficials, but *C.R. 409*[3] and *Isopestox*[4] give a very high mortality 64 hours after spraying. . . . while Schradan, in the experiments proved to be a selective insecticide, *C.R. 409* and *Isopestox* did not." They reported that when *C.R. 409* and *Isopestox* were applied to the soil or irrigation water these two non-selective insecticides became selective and behaved like schradan with nearly no effect on predators.

Hanna *et al.* (1952) cited experiences in the control of mealybugs on cacao trees with *C.R. 409* in which it was found that the number of coccinellids was reduced from 107 to 3, 6 weeks after application when applied as a soil treatment. They explained the reduction in population of these predators on the basis of a lack of sufficient mealybugs to support them. Jeppson *et al.* (1952) used both Systox and schradan as trunk treatments to control citrus red mite on citrus thinking that this method of application would have the advantage of not affecting natural enemies of the mite.

Reynolds *et al.* (1953) reported that *Orius tristicolor* (White) was the only species affected of several important beneficial insects in cotton when it was sprayed with Systox.

PROCEDURE.—Large populations of the cotton aphid, *Aphis gossypii* Glover used as a source of food for the various predators were maintained on Deltapine 15 cotton grown in soil beds in a greenhouse. Frequent applications of methoxychlor were made to control parasites so that high populations of aphids could be maintained. Colonies of three species of syrphids, *Baccha clavata* (F.), *Metasyrphus wiedemanni* (Johnson) and *Allograpta obliqua* (Say) were maintained on these plants. Five species of coccinellids, *Scymnus haemorrhous* Lec., *S. creperus* Muls., *Hippodamia convergens* (Chev.), *Coleomegilla maculata* (Deg.), *Cycloneda sanguinea* (L.) and two species of lacewings, *Chyrsopa rufilabris* Burmeister and *C. oculata* Say[5], were reared in screen cages 14 by 14 by 18 inches in size. Potted cotton plants heavily infested with the cotton aphid were used to supply food. The cages were examined each day and eggs were removed to petri dishes where they were left until the larvae hatched. First instar larvae were used in all tests except in the case of the syrphids where middle instars and full grown larvae were used.

To obtain poisoned aphids on which to feed the predators, cotton leaves heavily infested with the cotton aphid were clipped from the plants and treated with Systox[6], principally 0, o-diethyl-0-2-(ethylmercapto)-ethyl thiophosphate, diluted 1 part to 800 parts of water. Where the radioactive material was studied

[1] The data in this paper are taken in part from a dissertation submitted by Mostafa Kamal Ahmed in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Entomology, Louisiana State University, Baton Rouge, Louisiana.

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[3] Bis-(mono-isopropyl amido)-fluorophosphine oxide.

[4] Bis-(dimethyl amido)-fluorophosphine oxide.

[5] All insects identified by the Division of Insect Identification, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

[6] Furnished by the Chemagro Corporation.

Table 1.—The effect of feeding cotton aphids killed by Systox to three species of syrphid larvae.

| Species | Category | Individuals Tested | Insects Dead on Day Indicated | | | | | | | Per Cent Killed |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | |
| *Baccha clavata* | Treated | 109 | 49 | 36 | 16 | 4 | 1 | | | 97.8 |
| | Check | 109 | 0 | 0 | 0 | 0 | 0 | | | |
| *Metasyrphus wiedemanni* | Treated | 101 | 38 | 52 | 6 | | | | | 98.3 |
| | Check | 101 | 0 | 0 | 0 | | | | | |
| *Allograpta obliqua*[1] | Treated | 102 | 23 | 39 | 31 | 9 | | | | 100 |
| | Check | 102 | 0 | 0 | 0 | 0 | | | | |
| *Allograpta obliqua* | Treated | 96 | 5 | 11 | 12 | 18 | 10 | 7 | 1 | 67.2 |
| | Check | 96 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

[1] Middle larval instars were used; full grown larval instars used in other tests.

Systox[7] tagged with $S^{35}$ having a specific activity of 4.7 millicuries per milligram was used at the same concentration. The upper surface of the leaf was painted thoroughly with the diluted Systox by means of a cotton swab. A second application was made after the first had dried. After a 15-minute period which allowed the second application to dry the leaves were placed lower surface up on a sheet of clean paper. By this method all the aphids killed were saved since the leaves were lying flat and the aphids which crawled from the leaves were caught on the sheet of paper. This technique allowed for the use of aphids poisoned by Systox without any external contact with the insecticide. When most of the aphids had become moribund—after 2 or 3 hours—they were brushed from the treated leaves with a camel's-hair brush onto an untreated leaf in a petri dish. Five to 10 predators in the larval stage, or not more than five in the adult stage, were placed in each dish. A piece of dark paper was fitted inside the cover of each dish to keep the insects near their food instead of being attracted by the light to the tops of the dishes. Appropriate controls were conducted by using unpoisoned aphids as a source of food. A fresh supply of food was given the predators twice each day for a period of 1 week. Counts were made each day of the living, moribund, and dead predators and of those that had pupated. Pupae were considered alive in all experiments. Abbott's formula (1925) was used in calculating percentage kill.

Predators fed aphids killed by feeding on leaves treated with radioactive Systox were dried at 110 degrees C. for 24 hours, ground to a powder, placed in small glass vials and stored over calcium chloride in a dessicator until ready for assaying radioactivity. For counting, a sample from each vial was transferred to a watch glass 26 mm. in diameter. The mounted sample was then placed in a reproducible position beneath the window of a Geiger-Muller end-window tube which was installed in a vertical lead shield. This equipment was operated in an insulated room in which the temperature was maintained at about 70 degrees F. and the relative humidity at about 50 per cent. Counting rates were corrected for background, resolving time, and progressive decay of the $S^{35}$ to give values in terms of number of counts per minute per milligram of sample. Care was taken to use approximately equal amounts of each sample and to distribute them over the watch glasses in such a manner as to present approximately equivalent surface areas for measurement.

DISCUSSION OF RESULTS.—The results are presented in tables 1 to 8 inclusive. Syrphid larvae were highly susceptible to Systox when fed on aphids poisoned by feeding on cotton leaves treated with the material. All instars were susceptible except full grown larvae of *Allograpta obliqua*. Last instar larvae of this species were somewhat resistant to Systox. Larvae of *Baccha clavata* and *Metasyrphus wiedemanni* fed on posioned aphids for a period of 24 hours and then became moribund. All became moribund after the first day; and most of them died within 3 days. All of the individuals of *A. obliqua* fed poisoned aphids during the early or

[7] Prepared at Oklahoma A & M College and furnished by Chemagro Corporation.

**Table 2.—Counts per minute per milligram of syrphid larvae and pupae fed on aphids killed by 1:800 radioactive Systox.**

| STAGE | COUNTS PER MINUTE PER MILLIGRAM OF SAMPLE | |
|---|---|---|
| | *Allograpta obliqua*[1] | *Metasyrphus wiedemanni*[2] |
| Larvae | 1.89 | .85 |
| Pupae | 1.11 | .18 |

[1] The larvae died or pupated after 48 hours.
[2] The larvae died or pupated after 24 hours.

middle instars died within 4 days. However, only 67.2 per cent of the full grown larvae died after being fed on the poisoned aphids and the remainder were able to pupate (Table 1). Apparently normal adults emerged from individuals which pupated. Full grown larvae of this species did not become moribund until the second day of feeding on poisoned aphids and were able to survive in contrast to larvae of the other two species. When full grown larvae of *A. obliqua* and *M. widemanni* were killed by being fed aphids poisoned with radioactive Systox they showed radioactivity of 1.89 and 0.85 counts per minute per milligram respectively which again indicates that *A. obliqua* is more resistant (Table 2).

The five species of coccinellid larvae were affected by Systox in the following decreasing order of susceptibility: *Scymnus haemorrhous*, *Cycloneda sanguinea*, *S. creperus*, *Hippodamia convergens* and *Coleomegilla maculata* (Table 3). Larvae of *C. maculata* were almost immune to Systox when fed poisoned aphids. Larvae of *S. haemorrhous* were susceptible in all instars but the last instar larvae of the other species were able to survive feeding on poisoned aphids until they pupated. Larvae of *H. convergens* which were able to survive feeding on aphids poisoned by radioactive Systox showed less radioactivity than individuals which were not able to survive when fed in the same manner for the same period of time (Table 4). The radioactive material apparently accumulates in the body of the larvae since third instar larvae and fifth instar larvae which survived treatment contained 4.26 and 7.29 counts per minute per milligram, but those killed by the treatment contained 22.80 and 15.32 counts per minute per milligram respectively (Table 4).

**Table 4.—Counts per minute per milligram of *Hippodamia convergens* larvae when fed on cotton aphids killed with radioactive Systox beginning at the first larval instar.**

| STAGE | NUMBER OF FEEDING DAYS | COUNTS PER MINUTE PER MILLIGRAM OF SAMPLE | |
|---|---|---|---|
| | | Alive | Dead |
| 3rd instar | 5 | 4.26 | 22.80 |
| 5th instar | 8 | 7.29 | 15.32 |

Adults of the same five species of coccinellids were much more resistant to Systox than their larvae except in the case of *Cycloneda sanguinea* where 56 per cent of the individuals used in tests were killed (Table 5). Adult *Hippodamia convergens* showed much less radioactivity than their larvae when both were fed on poisoned aphids. Radioactivity measured in adults of this species which emerged

**Table 3.—The effect of feeding cotton aphids killed by Systox to five species of Coccinellid larvae.**

| SPECIES | CATEGORY | INDIVIDUALS TESTED | INSECTS DEAD ON DAY INDICATED | | | | | | | PER CENT KILLED |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | |
| *Scymnus haemorrhous* | Treated | 108 | 47 | 39 | 16 | 5 | 1 | | | 100 |
| | Check | 108 | 0 | 0 | 0 | 0 | 0 | | | |
| *Scymnus creperus* | Treated | 164 | 69 | 21 | 28 | 9 | 6 | 3 | | 79.5 |
| | Check | 164 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| *Cycloneda sanguinea* | Treated | 138 | 2 | 18 | 19 | 18 | 26 | 21 | 18 | 88 |
| | Check | 138 | 5 | 0 | 7 | 2 | 2 | 1 | 0 | |
| *Hippodamia convergens* | Treated | 97 | 2 | 6 | 9 | 18 | 20 | 6 | 6 | 51.6 |
| | Check | 97 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | |
| *Coleomegilla maculata* | Treated | 103 | 2 | 2 | 0 | 0 | 1 | 0 | 0 | 3.7 |
| | Check | 103 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | |

**Table 5.—The effect of feeding cotton aphids killed with Systox to five species of Coccinellid adults.**

| Species | Category | Individuals Tested | Insects Dead on Day Indicated | | | | | | | Per Cent Killed |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | |
| *Scymnus haemorrhous* | Treated | 102 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | .95 |
| | Check | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| *Scymnus creperus* | Treated | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Check | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| *Cycloneda sanguinea* | Treated | 101 | 0 | 4 | 11 | 11 | 11 | 11 | 8 | 56 |
| | Check | 101 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| *Hippodamia convergens* | Treated | 100 | 0 | 1 | 0 | 2 | 0 | 1 | 2 | 6.3 |
| | Check | 100 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | |
| *Coleomegilla maculata* | Treated | 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Check | 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

**Table 6.—Counts per minute per milligram of *Hippodamia convergens* adults fed for various periods of time on cotton aphids killed by radioactive Systox.**

| Number of Feeding Days | Counts per Minute per Milligram |
|---|---|
| 3 | 0.56 |
| 6 | 0.65 |
| 9 | 1.23 |
| 12 | 1.21 |
| 15 | 0.80 |
| 18 | 1.03 |

**Table 7.—Counts per minute per milligram of *Hippodamia convergens* prepupae and adults after feeding the larvae on aphids killed with radioactive Systox.**

| Number of Feeding Days | Counts per Minute per Milligram of Sample | | |
|---|---|---|---|
| | Prepupae | Adults | Cast Pupal Skin |
| 2 | .91 | .75 | — |
| 3 | 1.99 | 1.30 | — |
| 7 | 4.51 | 2.49 | — |
| 9 | 7.70 | 6.48 | 44.03 |

from larvae fed poisoned aphids, showed less radioactivity than larvae in the prepupal stage (Table 7). Lower counts obtained from the adults were due, at least in part, to the loss with the cast pupal skin which showed much more radioactivity than the adult or the larvae (Table 7). This cast skin consists of both the last larval instar skin and the pupal skin. There may also be an accumulation of the material in the body of the adults as well as in the larvae. Adults fed for 3 days on aphids poisoned with the radioactive material showed 0.56 counts per minute per milligram compared to 1.03 counts per minute per milligram for those fed for 18 days (Table 6).

All stages of larvae of *Chrysopa oculata* and *C. rufilabris* were practically immune to Systox when fed cotton aphids poisoned by the material. Only 2 per cent of the entire number tested of both species died (Table 8). Larvae of *Chrysopa oculata* fed for a period of 8 days on aphids killed with radioactive Systox showed

**Table 8.—The effect of cotton aphids killed by Systox when fed to first instar larvae of two species of *Chrysopa*.**

| *Chrysopa* Species | Category | Individuals Tested | Insects Dead on Day Indicated | | | | | | | Per Cent Killed |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | |
| *rufilabris* | Treated | 105 | 0 | 1 | 2 | 2 | 0 | 0 | 1 | 2 |
| | Check | 105 | 2 | 0 | 0 | 1 | 0 | 0 | 2 | |
| *oculata* | Treated | 112 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 2 |
| | Check | 112 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | |

1.54 counts per minute per milligram but were able to survive.

SUMMARY.—The indirect effect of Systox on several species of predaceous insects was studied by feeding them on cotton aphids poisoned with the insecticide. Three species of Syrphidae tested were highly susceptible in all larval stages. Susceptibility of larvae of five species of Coccinellidae tested ranged from 100 per cent in *Scymnus haemorrhous* to 3.7 per cent in *Coleomegilla maculata*. Adult Coccinellidae fed on poisoned aphids were not affected except for *Cycloneda sanguinea* of which about 50 per cent were killed. Larvae of two species of *Chrysopa* were practically immune to Systox.

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# Biology and Control of *Brevipalpus inornatus* (Banks)[1]

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Although several investigators have made observations relating to the taxonomy of the privet mite, *Brevipalpus inornatus* (Banks), very little has been reported concerning its life history. Such a study appears desirable in view of the considerable amount of damage it causes to ornamental plants and, in certain parts of the world, to citrus.

Following Banks' description (1912) of the mite, the first report of damage caused by this arachnid was that of McGregor (1914) who found it to be extremely destructive to privet hedges in South Carolina. Later, McGregor (1916) published the results of a few field observations concerning the biology of the mite. Smith (1943) described the privet mite as being a serious pest of fuchsias in California. Essig (1944) considered its importance to privet in the same state, and Pritchard (1949) reported further concerning its importance on azaleas and certain other ornamentals. A serious disease, *lepra explosiva*, of orange in Argentina, originally attributed to a fungus (Marchinatto 1935) and later regarded as being caused by a virus (Marchinatto 1938, Blanchard 1939), is now believed to be the result of a toxin injected by the mite in the process of feeding (Vergani 1945). The writer has recently observed the mite causing very serious damage to anthuriums and orchids in nurseries on the island of Oahu and in southern California. The present report is primarily concerned with a detailed study of the life history of the mite under controlled laboratory conditions as well as with certain observations relating to its distribution and taxonomic characteristics. Field observations were made in the vicinity of Berkeley, following a recent outbreak in that area.

TAXONOMIC STATUS.—*Tenuipalpus inornatus* Banks (1912) was described from Batesburg, South Carolina, on goldenrod. *Tenuipalpus bioculatus* McGregor (1914) was described from the same locality on privet. Baker (1945), in a review of the

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**List of host plants of Brevipalpus inornatus (Banks).**

| PLANT FAMILY | PLANT SPECIES | FOUND BY | IDENTIFIED BY |
|---|---|---|---|
| Araceae | Anthurium sp. | Morishita | Pritchard |
| | Schistomaglotis latifolia | Morishita | Morishita |
| Araliaceae | Aralia sp. | Pritchard | Pritchard & Baker |
| | Hedera helix | Essig | Pritchard & Baker |
| | Trevesia micholitzii | Morishita | Morishita |
| Begoniaceae | Begonia sp. | Baker | Baker |
| Campanulaceae | Campanula sp. | Pritchard | Pritchard & Baker |
| Caprifoliaceae | Jap. honeysuckle | Baker | Baker |
| Compositae | Crysanthemum | Summers | Pritchard & Baker |
| | Gazania sp. | Pritchard | Pritchard & Baker |
| | Gerbera sp. | Pritchard | Pritchard & Baker |
| | Goldenrod | Banks | Banks |
| | Ligularia kaempferi | Morishita | Morishita |
| Ericaceae | Azalea | Banks | Banks |
| Labiatae | Coleus sp. | Banks | Banks |
| | Mentha spicata | McGregor | McGregor |
| | Sage | Womersley | Pritchard & Baker |
| Liliaceae | Aspidistra | Pritchard | Pritchard & Baker |
| | Tulip bulb | Baker | Baker |
| Malvaceae | Hibiscus | Baker | Baker |
| Melastomaceae | Osbeckia sp. | Baker | Baker |
| Oleaceae | Ligustrum sp. | McGregor | McGregor |
| Onagraceae | Fuchsia sp. | Smith, R. H. | Pritchard & Baker |
| Orchidaceae | Dendrobium sp. | Pritchard | Pritchard & Baker |
| Oxalidaceae | Oxalis stricta | McGregor | McGregor |
| Palmaceae | Phoenix humilis | Baker | Baker |
| | Phoenix roebelini | Pritchard | Pritchard & Baker |
| Pittosporacea | Pittosporum | Baker | Pritchard & Baker |
| Polygonaceae | Rumex actosella | McGregor | McGregor |
| Rosaceae | Boysenberry | Smith, R. F. | Pritchard & Baker |
| | Cotoneaster sp. | Morishita | Pritchard & Baker |
| | Potentilla anserina | Pritchard | Pritchard & Baker |
| | Strawberry | McGregor | McGregor |
| Rutaceae | Citrus sp. | Baker | Baker |
| Solanaceae | Potato shoots | Bartlett | Baker |
| Theaceae | Tea | Gadd | Baker |
| Verbenaceae | Citharexylum quadrangularis | Baker | Baker |
| Violacea | Viola sp. | Morishita | Pritchard & Baker |
| Vitaceae | Boston ivy | McGregory | McGregor |

genus *Tenuipalpus*, transferred *inornatus* to the genus *Brevipalpus*. McGregor (1949) regarded *bioculatus* as a synonym of *inornatus*. *Tenuipalpus pseudocuneatus* Blanchard (1939), described from citrus in Argentina, was shown by Pritchard and Baker (1951) also to be a synonym of *Brevipalpus inornatus*.

DISTRIBUTION AND HOST PLANTS.—*Brevipalpus inornatus* is widespread in distribution, and there is no indication, at the present, as to its origin. The records of occurrence as shown in the accompanying list may be accepted as authentic. The privet mite feeds on a number of hosts. The accompanying list shows all of the hosts for which records are available.

DESCRIPTION.—*Egg.* The egg is elliptical. It is bright orange-red in color when first deposited, later becoming slightly darker. As the incubation period progresses, it increases slightly in size. Just prior to hatching, the anterior end becomes swollen, and the chorion assumes an opaque, white appearance.

*Larva.* The newly emerged larva (Fig. 1) is orange-red in color, although dark areas appear on the hysterosoma after feeding starts. The body is broadest at the propodosoma, and the lateral margins of the hysterosoma converge posteriorly. The rostral shield is not developed. Propodosomal seta I is very short; propodosomal seta II, just anterior to the compound eye, is moderately long, lanceolate and serrate; propodosomal seta III is similar to II but longer. Marginal setae I-III of the hysterosoma are very short and similar to propodosomal I; IV and V are long, lanceolate, serrate, and about the same size as the propodosomal III; V is very long and filiform. The larva measures about 0.150 mm. in length.

*Protonymph.* The protonymph differs

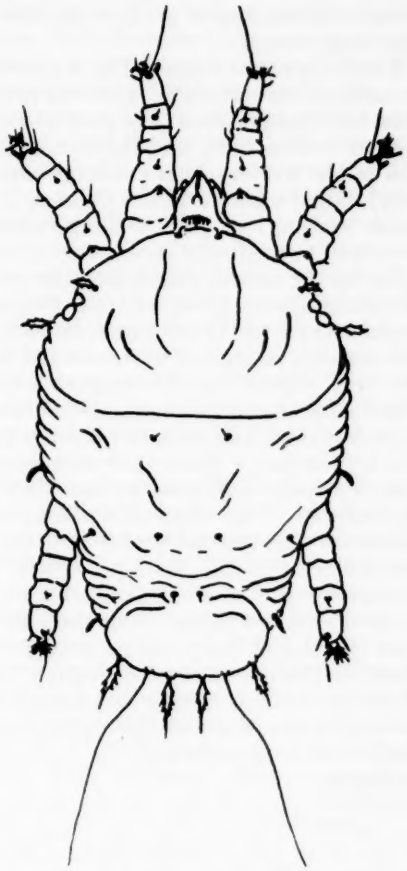

FIG. 1.—Dorsal view of larva of *Brevipalpus inornatus* (Banks).

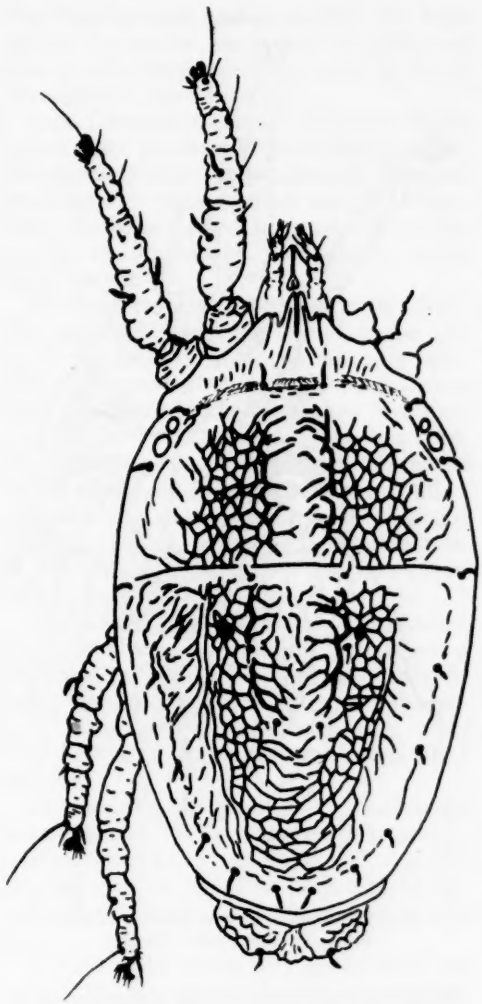

FIG. 2.—Dorsal view of adult female of *Brevipalpus inornatus* (Banks).

**World distribution of *Brevipalpus inornatus* (Banks).**

| CONTINENT | AREA | FOUND BY | IDENTIFIED BY |
|---|---|---|---|
| Europe | Italy | Baker (1949) | Baker (1949) |
| Asia | Ceylon | Baker (1949) | Baker (1949) |
| | Japan | Baker (1949) | Baker (1949) |
| North America | Canada | Baker (1949) | Baker (1949) |
| | So. Carolina | Banks (1912) | Banks (1912) |
| | California | Smith (1943) | Pritchard & Baker (1951) |
| | Florida | Baker (1949) | Baker (1949) |
| | Louisiana | Baker (1949) | Baker (1949) |
| | Maine | Baker (1949) | Baker (1949) |
| | Maryland | Baker (1949) | Baker (1949) |
| | Missouri | Baker (1949) | Baker (1949) |
| | Oregon | Baker (1949) | Baker (1949) |
| | Texas | Baker (1949) | Baker (1949) |
| | Washington | Baker (1949) | Baker (1949) |
| | New Jersey | Hamilton (1953) | Baker (1952) |
| South America | Argentina | Blanchard (1939) | Pritchard & Baker (1951) |
| | Venezuela | Baker (1949) | Baker (1949) |
| Australia | Adelaide | Womersley (1940) | Pritchard & Baker (1951) |
| Pacific Islands | Hawaii | Morishita (1953) | Pritchard (1953) |

from the larva principally by possessing four pairs of legs. The coloration is about the same as that of the larva just prior to the quiescent phase. The body is broadest at the propodosoma, and the lateral margins of the hysterosoma converge posteriorly. Dorsal seta I of the propodosoma is very short and, in many cases, serrate; II and III are quite long, broadly lanceolate and serrate. Marginal hysterosomals I to III are very short and similar to propodosomal I; IV and VI are all similar in length, size and shape to propodosomals II and III. The protonymph measures about 0.214 mm. in length.

*Deutonymph.* The deutonymph is very

FIG. 3.—Ventral view of adult female of *Brevipalpus inornatus* (Banks).

similar to the protonymph, differing mainly in being larger in size. The deutonymph measures about 0.256 mm. in length.

*Adult female.* The variation in color of female is great, ranging from light orange to dark red with various patterns of dark pigmentation (Fig. 4). The newly emerged females often possess small areas of black pigment (Fig. 4A). After feeding takes place, the black areas increase in size (Fig. 4B to F). The extent of the dark pigment is apparently correlated with the amount of feeding, although the rate of increase varies greatly. In a few instances, the color change is completed in one day, while in the majority of the cases, it is a gradual change which requires from 3 to 7 days. Many mites tend to lose the black coloration at the end of their normal life span, and may revert to the condition shown in fig. 4A or B. This is particularly true of females depositing a greater number of eggs than average.

The body of the female (Fig. 2 and 3) is broadest at the suture between the prodosoma and hysterosoma. The propodosoma is shorter than wide, and the lateral margins of the hysterosoma converge posteriorly. Palpal segment II has a sharp, inner basal swelling. A pair of long, median lobes and two pairs of small, lateral lobes make up the rostral shield, and the proximal margin is finely reticulated. Propodosomal setae I to III are short, lanceolate, and serrate. Marginal hysterosomal I-VI are very similar to the propodosomals. The dorsum has rather even, mediolateral reticulations. Hysterosomal pores are present, but in many cases their tubular nature is weakly indicated or else they are semitubular. The ventral reticulate elements on the ventral plates and on the area anterior to the plates are small. The posterior pair of medioventral setae on the hysterosoma are longer than the anterior pair. Tarsus II has a single sensory rod distally. The dorsal setae of femora I and II are lanceolate, serrate and almost half as long as the width of the segment. The adult female measures about 0.278 mm. in length.

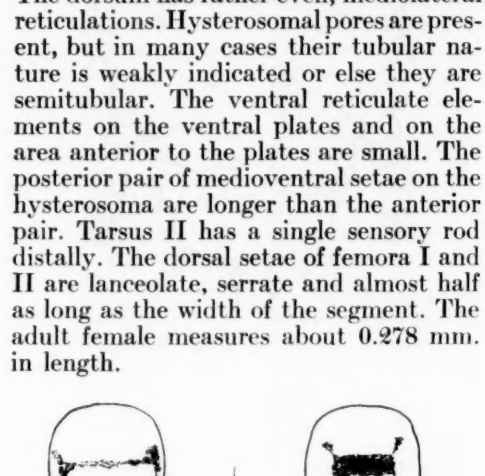


FIG. 4.—Variation in color patterns of adult females of *Brevipalpus inornatus* (Banks).

*Adult male.* The male is similar to the female. Palpal segment II does not have a sharp, inner basal swelling. The male measures about 0.261 mm. in length.

FEEDING.—The mites feed on the ventral surface of the leaves and the stems and petioles. Smith (1943), summarizing the feeding injury of the privet mite on fuchsias, states, "Faint brown flecks form the first evidence of injury. Examination under a microscope reveals that each fleck is a sunken spot where the substance of cells has been sucked out, or the cells have been poisoned as a result of the feeding. The mite feeds by stabbing the cells repeatedly, then exuding saliva on the wounded tissue and sucking up the resulting mixture of saliva and cell substance. With prolonged infestation the flecks merge together and large portions of the leaf, or the entire lower surface, become brownish or bronzy in color. At this stage a deep red discoloration develops on the top side of the leaves of most varieties. This discoloration is usually limited at first to the portions of the leaf which were first infested. Leaf drop begins to occur about the time the red discoloration develops. At the time this is written (July 22, 1943) it appears that in some sections a large percentage of fuchsia plants will be well defoliated before fall." A similar type of injury occurs on azaleas, accompanied by discoloration and defoliation. The feeding injury on anthuriums is a little different in that the dorsal surface of the leaf will start to have yellowish areas and the ventral surface becomes brownish where the feeding has taken place. Leaf drop will occur where a heavy infestation of mites develops.

OVERWINTERING.—Limited observations made in Berkeley, California, indicate that the winter is passed mostly in the adult stage in this area. They are usually found at the base of plants or in sheltered places on the ventral surface of the leaves. A few eggs may be observed throughout the winter on violets, these occurring mostly in sheltered locations such as in exuviae, among lesions caused by leaf injury, under the bases of trichomes, or near dirt accumulated on the ventral surface of the leaves. Immature stages are seldom observed during the winter months, and they scarcely move even when disturbed with a brush or a dissecting needle. In greenhouses, where the temperature and humidity are kept within favorable limits for reproduction and development, all stages may be found throughout the winter.

SEX DETERMINATION.—Females of the privet mite produce female offspring parthenogenetically. Approximately 20 generations were reared under various laboratory conditions, and no males were encountered. In nature, males have rarely been found.

STUDIES ON DEVELOPMENT.—*Methods.* The garden violet was found to be the most practical host for laboratory use. Violet leaves with petioles 5 to 6 inches long were selected. Cotton was wrapped around the petioles, about 3 inches from the base, and the cotton plug then fitted into a glass vial (27 mm.×80 mm.) filled with water. Leaves were usually changed weekly, but at controlled temperatures of 32° and 30° C. the leaves were often changed every third day.

No barriers or areas of confinement were used, since the mites would remain on a healthy leaf under experimental conditions. When petroleum jelly or "tanglefoot" was used as a barrier, the mites would invariably crawl into the material and die.

Developmental studies at controlled temperatures were conducted in temperature cabinets at 15°, 25°, 27°, 30°, and 32° Centigrade. The relative humidity of the cultures was kept at approximately 85 per cent.

A culture of mites was maintained at each of the experimental temperatures before individuals were isolated for studies on development and reproduction at that temperature. Observations of life histories were made twice daily.

*Egg.* Just prior to hatching, movement of the larva within the chorion may be observed. At eclosion, the chorion splits transversely with respect to the main axis near the anterior or swollen end and the larva crawls out.

Observation (Table 1) indicated that the minumum time required for incubation is 5 days at 32° C. However, at this temperature only about 47 per cent of the eggs hatched. At 20° C., the average time required for hatching was found to be 15.4 days, the maximum being 17 days and the minumum 14 days. At 15° C. none of the eggs hatched. Eggs were maintained at this temperature for 2 months, and at

Table 1.—Effect of temperature on incubation of eggs.

| Temperature (Degrees C.) | Eggs | | Incubation Period—Days | | |
|---|---|---|---|---|---|
| | Number | Hatched | Maximum | Minimum | Average |
| 32 | 72 | 34 | 8 | 5 | 5.8 |
| 30 | 72 | 72 | 7 | 5 | 6.1 |
| 27 | 78 | 78 | 8 | 6 | 7.0 |
| 25 | 90 | 90 | 9 | 8 | 8.8 |
| 20 | 102 | 102 | 17 | 14 | 15.4 |

the end of this time the chorion was translucent white with a very small red area at one end. The eggs were then transferred to the 27° cabinet to determine their viability, and their appearance was unchanged at the end of 2½ weeks.

*Immature stage.* As in the case of most other mites, the privet mite has a larval and two nymphal instars. Each instar is divided into a feeding, or active, period and a quiescent period that precedes molting. During quiescence, the chelicerae are inserted in the plant tissue for anchoring. The anterior pairs of legs are stretched directly forward, and the posterior pairs of legs are stretched posteriorly and held adjacent to the hysterosoma. In the process of molting, the dorsal suture between the hysterosoma and propodosoma separates, and the lateral margins of the hysterosoma split. The emerging mite usually frees the posterior portions of its body first and pulls out its anterior portion afterwards. The dorsum of the hysterosomal exuvia often adheres to a recently molted mite.

Under experimental conditions death usually occurs at the end of the active or during the quiescent period. Due to the difficulty of determining the exact time of death, it is arbitrarily considered to be immediately after the active phase. As shown in table 2, the total time required for the immature stages ranges from 10.3 days (at 30° C.) to 26.6 days (at 20° C.).

*Larva.* The newly emerged larva wanders near the egg shell for an hour or so before starting to feed. A well-protected place near the chorion, such as the base of a trichome, the junction of a vein and mid-rib, or a crack, is chosen for the initial quiescent period. The length of the active larval stage ranges from 1 day (at 32° C.) to 7 days (at 20° C.). About 85 per cent mortality occurs with larvae exposed to

Table 2.—Effect of temperature on development of immature stages.

| Temperature (Degrees C.) | Number | Number of Days | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Active | | | Quiescent | | | Total | | |
| | | Max. | Min. | Average | Max. | Min. | Average | Max. | Min. | Average |
| *Larva* | | | | | | | | | | |
| 32 | 34 | 4 | 1.0 | 2.0 | 3 | 1.0 | 1.9 | 7 | 2.0 | 3.9 |
| 30 | 72 | 3 | 1.0 | 2.1 | 2 | 1.5 | 1.4 | 5 | 2.5 | 3.5 |
| 27 | 78 | 4 | 2.5 | 3.2 | 3 | 1.5 | 2.1 | 7 | 4.0 | 5.3 |
| 25 | 90 | 6 | 4.0 | 5.0 | 3 | 2.0 | 2.1 | 9 | 6.0 | 7.1 |
| 20 | 102 | 7— | 5.0 | 5.6 | 5 | 3.0 | 3.9 | 12 | 8.0 | 9.5 |
| *Protonymph* | | | | | | | | | | |
| 32 | 14 | 3 | 1 | 1.7 | 1 | 1.0 | 1.0 | 4 | 2.0 | 2.7 |
| 30 | 72 | 3 | 2 | 2.1 | 3 | 1.0 | 2.0 | 6 | 3.0 | 4.1 |
| 27 | 78 | 3 | 2 | 2.1 | 2 | 1.5 | 1.9 | 5 | 3.5 | 4.0 |
| 25 | 90 | 4 | 2 | 3.0 | 3 | 1.5 | 2.0 | 7 | 5.0 | 5.0 |
| 20 | 96 | 5 | 3 | 3.9 | 5 | 3.0 | 4.0 | 10 | 6.0 | 7.9 |
| *Deutonymph* | | | | | | | | | | |
| 32 | 4 | 4 | 3 | 3.5 | 1.0 | 1.0 | 1.0 | 5.0 | 4.0 | 4.5 |
| 30 | 72 | 3 | 1 | 1.9 | 1.5 | 0.5 | 0.75 | 4.5 | 1.5 | 2.7 |
| 27 | 78 | 3 | 2 | 2.2 | 2.0 | 1.5 | 1.9 | 5.0 | 3.5 | 4.0 |
| 25 | 90 | 5 | 3 | 4.1 | 4.0 | 2.0 | 3.0 | 9.0 | 5.0 | 7.1 |
| 20 | 96 | 5 | 3 | 4.1 | 6.0 | 4.0 | 5.1 | 11.0 | 7.0 | 9.2 |
| *Combined Total* | | | | | | | | | | |
| 32 | | | | | | | | 16.0 | 8.0 | 11.1 |
| 30 | | | | | | | | 15.5 | 7.0 | 10.3 |
| 27 | | | | | | | | 17.0 | 11.0 | 13.3 |
| 25 | | | | | | | | 25.0 | 16.0 | 19.2 |
| 20 | | | | | | | | 33.0 | 21.0 | 26.6 |

32° C., although many live for a day or two before dying. The quiescent stage lasts from 1 day (at 32° C.) to 5 days (at 20° C.).

*Protonymph.* The protonymph moves away from the immediate vicinity of the exuviae and selects an area in which it remains to feed. The feeding injury becomes noticeable as blackened areas develop. The active phase of the protonymphal stage lasts from 1 day (at 32° C.) to 5 days (at 20° C.). The rate of mortality at 32° C. is close to 95 per cent. The quiescent phase ranges from 1 day (at 32° C.) to 5 days (at 20° C.).

*Deutonymph.* The habits of the deutonymphs are quite similar to those of the protonymph. The duration of the active period of the deutonymph ranges from 1 day (at 30° C.) to 5 days (at 20° C.). The quiescent phase lasts from ½ day (at 32° C.) to 6 days (at 20° C.).

*Adult female.* The privet mite does not ordinarily show any great tendency to move about. When disturbed, however, females move to a leaf area some distance away from the original point. The temperature has a great effect on their movements, and at high temperatures they become very active. The preoviposition period ranges from 1½ days (at 27° C.) to 7 days (at 20° C.). It appears that the mites must feed before depositing eggs. The oviposition period ranges from 20 days (at 30° C.) to 50 days (at 20° C.). The maximum number of eggs (table 3) deposited per female is 60 (at 27° C.), each mite depositing from one to two eggs daily. At 20° C., the oviposition is very irregular, the interval between egg deposition varying from 2 to 8 days or, in some cases, without oviposition occurring.

The maximum length of life of females (Table 3) is 75 days (at 20° C.). A female that did not deposit any eggs at 20° C. for 22 days was transferred to the 25° C. cabinet, and in 4 days the first egg was deposited. The minimum length of life is 19 days at 30° C.

**Table 3.—Effect of temperature on longevity and egg production of adult females.**

| Temperature (Degrees C.) | Number | Length of Adult Life | | | Number of Eggs | | |
|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 32 | 2 | 3 | 3 | 3.0 | 1 | 0 | 0.5 |
| 30 | 72 | 26 | 19 | 23.4 | 38 | 26 | 32.1 |
| 27 | 78 | 40 | 35 | 38.1 | 60 | 49 | 54.3 |
| 25 | 90 | 58 | 50 | 52.5 | 54 | 40 | 44.1 |
| 20 | 96 | 75 | 62 | 67.0 | 5 | 0 | 3.0 |

**Table 4.—Control of *Brevipalpus inornatus* (Banks) with various acaricides, Los Angeles, California, 1953.**

| Material[1] | 1st Week | 2nd Week | 3rd Week |
|---|---|---|---|
| *Ovotran*, 25% | none[2] | none | few[3] |
| Chlorobenzilate, 25% | none | none | none |
| Aramite, 25% | few | few | few |
| DMC, 25% | none | none | none |
| Toxaphene, 60% | few | few | many[4] |
| Rotenone, 15% | many | many | many |
| Malathion, 50% | few | many | many |
| Diazinon, 25% | none | none | none |
| Check | many | many | many |

[1] All materials were emulsions used at a dosage of 1 to 800 except Diazinon was wettable powder used at 2 pounds per 100 gallons.
[2] No living mites.
[3] Up to 25 per cent of original population level.
[4] Above 25 per cent of original population level.

CONTROL.—The privet mite is a pest principally on ornamentals, and only a limited amount of information has been available on its control. Pritchard (1949) found that the organic phosphates available then had no apparent effect on any of the economically important false spider mites in the San Francisco Bay area. Prior to Hamilton's work (1953), certain growers in the southern California area had reported that Aramite and malathion had been effective against certain false spider mites on greenhouse crops. In order to evaluate these, a screening test against the privet mite was started.

It was found during the course of this investigation that there were two species of *Brevipalpus* (*B. inornatus* and *B. australis*) involved and because of this the results were not consistent. Acaricidal tests against each species were made to see if there was any difference in their control. Preliminary tests showed that *B. australis* (Tucker) was the more susceptible of the two species to all of the acaricides tested.

The tests were made on aralia, ivy, and azalea heavily infested with the privet mite. The materials were: *Ovotran*[3], Chlorobenzilate (Geigy 338)[4], Aramite, DMC, toxaphene, rotenone, malathion, and Diazinon.

The results of these tests are shown in table 4. Each aralia leaf had approximately 400 active mites while each ivy and

[3] Trade name for p-chlorophenyl p-chlorobenzene sulfonate.
[4] Trade name for Geigy acaracide 4,4'-dichlorobenzilic acid ethyl ester.

azalea leaf had not less than 25 mites. Only one application was made, and mortality observations were made at weekly intervals for a period of 3 weeks to determine the residual effectiveness of the materials.

Chlorobenzilate, DMC and Diazinon gave the best control of the mite, while Aramite and *Ovotran* gave better control than did toxaphene, rotenone, and malathion. Diazinon is unique in that it is the only organic phosphate that has proven very effective for the control of the privet mite.

SUMMARY.—The privet mite, *Brevipalpus inornatus* (Banks), is widespread in distribution and feeds on a wide variety of host plants.

Parthenogenetic females give rise to only female progeny. Reproduction continues throughout the year under favorable conditions.

The incubation period of the egg ranges from 5 days (32° C.) to 17 days (at 20° C.). The larval stadium ranges from 3.5 days (at 30° C.) to 9.5 days (at 20° C.). The protonymphal stadium ranges from 2.7 days (at 30° C.) to 7.9 days (at 20° C.). The deutonymphal stadium ranges from 2.7 days (at 30° C.) to 9.2 days (at 20° C.). The minimum time required for development from hatching to adult is 7 days (at 30° C.), and the maximum time is 33 days (at 20° C.). The preoviposition period ranges from 1.5 days (at 27° C.) to 8 days (at 20° C.). The maximum length of life of an adult female is 75 days (at 20° C.). The maximum number of eggs per female is 60 (at 27° C.).

Chlorobenzilate, DMC and Diazinon gave the best control, while Aramite and *Ovotran* gave better-than-average control.

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# The Periodical Cicada in Southern Pennsylvania in 1953[1]

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In 1953, the anticipated emergence of Brood X of the periodical cicada, *Magicicada septendecim* (L.), was first observed in Southern Pennsylvania, near Arendtsville, on May 15. It continued in an erratic pattern until May 30. During this period, intermittent rains fell and there were not many hours of sunshine.

In connection with the emergence of Brood X, a point was noted which contributes evidence that cicada nymphs in orchard ground feed on tree roots rather than on other vegetation. In Adams County many old apple trees have been cut down in the last 5 or 6 years. Numerous old orchard sites have been replanted with young trees without disturbing the old sod cover crop. On such sites where the old trees were cut down in 1948 and 1949, no cicada nymphs emerged in 1953. Where the old trees were cut in 1950, a few cicadas emerged. More emerged in locations cut in 1951 and the emergence was as great on sites cleared in 1952 as on orchard land where the old trees are still standing. This indicates that as the old tree roots died, cicada nymphs feeding on them perished. They were not able to secure adequate nutrients from the grass roots right at hand.

Mating of the adults did not occur except in rarely observed instances until May 28. Oviposition began June 2. There was no single peak period. The oviposition rate was heavy from June 2 through June 5. It was light during the rain period June 6 to 8 and heavy again on June 9, 10 and 11. Rains and cloudy weather on June 12, 13 and 14 interrupted oviposition. In orchards isolated from woodlands, it did not become heavy again, but in woodlands and in orchards bordered by them, oviposition continued until June 25. Eggs deposited on June 2 and 3 began to hatch on July 23. Hatching continued for approximately 3 weeks.

INJURY TO FRUIT TREES.—Female cicadas made egg-slits in the twigs of all the common fruit trees in this area. Slit twigs were collected from apple, peach, pear, plum, sour cherry and sweet cherry trees. The injury was most severe on the first three species. In a few cases, the actual damage to peach trees was greater than to neighboring apple trees.

Unprotected young apple trees in heavily infested locations were severely injured. Data were taken on a tree 9 feet tall, with a trunk 6 inches in circumference, and a limb spread of 6 feet. Branch and twig growth measured 1758 linear inches. Female cicadas inflicted 4590 egg cuts on this growth, depositing an average of 22 eggs per slit or a total of 100,980 on the whole tree. At the base of the largest branch, which measured $3\frac{3}{4}$ inches in circumference, the egg-slits were arranged in eight parallel rows. The top growth on this tree was so severely cut that it gradually died back to the trunk.

CONTROL TESTS.—*In Young Apple and Peach Plantings.*—Many trees up to 3 years of age were successfully protected with coverings of cheese cloth or second-hand tobacco cloth. The tobacco cloth was the easier to handle and cost less than cheese cloth. Uncovered young apple trees interplanted in old orchards that were sprayed with TEPP were not injured enough by cicadas to justify the expense of covering them.

Trees in the 4- to 10-year age group were the most difficult to protect. Such trees were too big to cover easily, yet they were small enough to be seriously damaged by a relatively light infestation of cicadas. The most satisfactory control was obtained by spraying every 3 days with TEPP during the periods of heavy oviposition. A specific planting of 4-year old apple trees sprayed five times by the laboratory crew at Arendtsville were injured only slightly though continuously reinfested from two sides.

Newly planted peach trees were easily protected with paper fertilizer bags or newspaper so fastened that new twig

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[2] Acknowledgment is made of the valued assistance of Guy A. Herring, William L. Coradetti, and Glenn R. Herring.

growth could break through the top of the covering. Although cut with numerous egg-slits, uncovered 2- and 3-year old peach trees were not seriously damaged because they soon replaced injured twigs with new growth.

*In Bearing Apple and Peach Orchards.*—Cicadas were controlled in most orchards with sprays of TEPP (40 per cent). This pesticide was mixed at the rate of 6 liquid ounces per 100 gallons in dilute sprays and 1 pint in 100 gallons in 3X concentrate sprays.

In the majority of orchards that were not subject to reinfestation from outside sources, two sprays applied in the 5-day period following the start of mating practically eliminated the infestation. In orchards adjacent to woodland, however, it was necessary to spray as many as 5 or 6 times to protect the trees from serious injury. Some growers who own orchards in the latter type of location hired airplane applicators to spray the edges of the woodlands and the portions of their orchards bordered by them. One pint of TEPP (40 per cent) per acre applied in 4 gallons of oil carrier or water gave satisfactory control especially if the spraying was done during quiet weather.

Injury to apple fruit from TEPP sprays was not so great as had been anticipated. There was some typical TEPP spotting following applications by airplane and also following ground applications to fruit that had been exposed to strong sunlight for several hours before it was sprayed.

Numerous peach orchards were sprayed with TEPP alone and with TEPP mixed with the fungicide captan. Although the leaves of these trees developed a severe case of shot-holing, the crop on these trees was not lost as on some trees that had every twig cut to shreds by female cicadas.

*With sprays.*—As indicated by the author (1952), tests on control of cicadas with TEPP in Pennsylvania were based on the work of Woodside (1948) and Cutright & Parks (1949). These workers, however, employed only dilute spray mixtures in their tests. In view of the widespread use of concentrated sprays in Pennsylvania orchards, TEPP was tested alone and in combination with certain other insecticides and fungicides in a number of tests with concentrated sprays. These tests all followed the same pattern. A marked area of orchard was sprayed with an airblast rig. As soon as the spray was applied, 25 cicadas were collected from the sprayed trees and the cover crop and placed in a clean cage, 12×12×12 inches in size and covered with ¼-inch hardware cloth. At the same time, a group of cicadas was collected from an unsprayed section of orchard to serve as a check. Occasionally, 24, 26 or 27 specimens were collected instead of 25. The actual number of specimens was used in figuring each percentage (Table 1).

Cages of test specimens were placed in the insectary at the laboratory and counts were made in 24 hours. Specimens unable to move about were considered killed. At first, records were taken at 48- and 72-hour intervals, as well as at 24 hours. But after it was observed in the field that sprayed female cicadas continued to deposit eggs until they died, insecticides that did not kill within 24 hours were considered worthless. Also, sexing of specimens was discontinued because the difference between the reaction time of males and females was only a matter of 1 or 2 hours in most cases. This difference was not a factor at the 24-hour point.

**Table 1.—Control of adult periodical cicadas with concentrated sprays of TEPP.[1]**

| Pesticides per 100 Gallons | | Per Cent | |
|---|---|---|---|
| TEPP (Pints) | Others | Gallons per Acre | Control in 24 Hours |
| 0.5 | *Ferbam*,[2] 4½ lbs. 75% DDT, 2 lbs. | 75 | 80.0 |
| 0.5 | None | 75 | 88.0 |
| 1 | *Ferbam*, 4½ lbs. 75% DDT, 2 lbs. | 75 | 88.0 |
| 1 | None | 75 | 100.0 |
| 1 | *Ferbam*, 4½ lbs. 75% DDT, 2 lbs. | 100 | 100.0 |
| 1 | None | 100 | 100.0 |
| 1 | *TM 341*, 4½ qts. Lime, 4 oz. 75% DDT, 2 lbs. | 100 | 75.0 |
| 1 | Pheno-lead,[3] 15 lbs. | 100 | 80.2 |
| 1 | Captan,[4] 4½ lbs. 75% DDT, 2 lbs. | 100 | 84.0 |
| 0.75[5] | None | 100 | 91.4 |
| 1.5[5] | None | 100 | 93.2 |

[1] Single tests with 40 per cent (supplied by Tobacco By-Products and Chemical Corp.) except as noted.
[2] *Coromate*, made by Pittsburg Plate Glass Co.
[3] A mixture of 3 pounds of lead arsenate and 2 pounds of phenothiazine made by E. I. du Pont de Nemours & Co., Inc. (3 tests)
[4] Captan 50-W, made by Stauffer Chemical Co. (2 tests)
[5] Two tests.
[6] *Vapotone* XX contains 20 per cent TEPP; made by California Spray-Chemical Corporation. (2 tests)

Because the tests listed in table 1 were not all run on the same day, the percentage control obtained in each test was computed by using the formula of Abbott (1925).

In addition to the tests with TEPP, certain other insecticides were tried against adult cicadas. As reported by Hamilton (1953), malathion and parathion were relatively ineffective; CS-708 and TDE sprays and TEPP dusts also gave unsatisfactory results. In concentrated sprays, 9 pounds of 50 per cent methoxychlor W.P. in 100 gallons of water gave high kills in 48 hours, but the kill at the end of 24 hours was less than 30 per cent. Demeton (21.2 per cent) at the rate of 4 ounces in 100 gallons gave 65 per cent kill in 24 hours, an indication that further trials with higher concentrations may give promising results.

DISCUSSION.—Results in table 1 show that under the conditions of these tests 1 pint of 40 per cent TEPP in 100 gallons applied to one acre of orchard gave 100 per cent control of the periodical cicada. The addition of *TM 341*,[3] lime and DDT, phenothiazine, lead arsenate and soya bean flour, or captan and DDT reduced the effectiveness of TEPP. When ferbam and DDT were added to the 1 pint concentration of TEPP and applied at the rate of 100 gallons per acre, there was no reduction in control. However, control by this mixture was reduced 12 per cent when the dosage was cut to 75 gallons per acre. The 1 pint concentration of TEPP (40 per cent) at 75 gallons per acre gave higher control than 0.75 pint in 100 gallons to the acre. The control obtained with 0.75 pint of TEPP (40 per cent) in 100 gallons per acre was not significantly different from that obtained with 1.5 pints of TEPP (20 per cent) applied in the same gallonage.

SUMMARY.—Brood X of the periodical cicada, *Magicicada septendecim* (L)., emerged in May, 1953, in Southern Pennsylvania over a period of 16 days, probably because there were frequent rains and not many hours of sunlight during this time. Observations on emergence from old orchard sites from which the trees had been cut but the sod cover crop left undisturbed indicated that tree roots are the only source of food for cicada nymphs in orchard soil.

Apple, peach and pear trees were injured more severely than other trees. One- to 3-year old apple trees were most easily protected with coverings of netting unless situated as interplants in bearing orchards that were sprayed with TEPP. Apple trees 4 to 10 years old required at least 5 sprays of TEPP if located on sites subject to reinfestation from outside sources.

In producing apple orchards, cicadas were controlled by spraying with TEPP (40 per cent), 6 ounces per 100 gallons in dilute sprays and 1 pint per 100 gallons in concentrated sprays. The number of applications needed to protect an orchard depended on how much it was subject to reinfestation from woodland. Some orchards near woodland were successfully protected by spraying both the orchard and the woodland by airplane with TEPP (40 per cent), 1 pint per acre in 4 gallons of oil carrier or water.

Parathion, malathion, TDE, and CS-708 sprays, and TEPP dust were relatively ineffective. Methoxychlor gave higher kills, but was too slow in action. In one dilute spray demeton gave results good enough to warrant further tests at higher concentrations.

The addition of the following: phenothiazine-lead arsenate; TM 341, lime, and DDT; captan and DDT reduced the effectiveness of TEPP at the 1 pint per 100 gallons per acre dosage, but the addition of ferbam and DDT did not unless the dosage was reduced to 75 gallons per acre.

[3] 34 per cent solution of 2-heptadecyl glyoxalidine acetate in isopropanol.

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# Identity of *Tetranychus pacificus* and *mcdanieli*[1]

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About 1937 a tetranychid mite began to cause injury in apple orchards in the Pacific Northwest. It differed from the European red mite, *Metatetranychsu ulmi* (Koch), which had been injurious for at least 15 years before 1937, in that it was usually greenish in color, it spun a great deal more webbing, and it hibernated in the adult stage under bark scales and fallen leaves. This mite was first assumed to be the two-spotted spider mite, *Tetranychus bimaculatus* Harvey, and it was found on pear, cherry, and plum trees as well as apple. That it had been present for several years is shown by a reference to it and a record of a test of sulfur dust for its control made in 1924 by Newcomer & Yothers (1927, p. 16).

In order to determine the species present, in July 1938 E. A. McGregor and the writer made a trip through the area, including the Hood River Section of Oregon, the Yakima, Wenatchee, and Okanogan valleys of Washington, and the southern Okanagan area of British Columbia. They collected mites from apple and other plants in all these localities. Mr. McGregor identified these mites, as well as those in material from southern Oregon and southern Idaho, as follows:

| Locality | Plant | Species |
|---|---|---|
| Oregon: | | |
| Medford | Pear | *bimaculatus* and *carpini borealis*[1] |
| Talent | Chokecherry | *pacificus* |
| Parkdale (near Hood River) | Apple | *carpini borealis*[1] |
| | Thimbleberry | *pacificus* |
| Washington: | | |
| Grandview | Apple | *pacificus* |
| Wapato | Apple and milkweed | *pacificus* |
| Moxee | Hops | *bimaculatus* |
| Yakima | Apple | *pacificus* |
| Wenatchee | Apple | *pacificus* |
| Near Chelan | Apple | *pacificus* |
| Omak | Apple | *pacificus* |
| Oroville | Apple | *Tetranychus* sp. |
| British Columbia: | | |
| Penticton | Pear | *Tetranychus* sp. |
| Near Penticton | Antelope-brush | *willamettei* |
| Idaho: | | |
| Payette | Apple | *pacificus* |
| Parma | Apple | *pacificus* |

[1] Determined in 1938 as *willamettei*.

In Oregon the predominant tetranychid on apple and pear was *Eotetranychus carpini borealis* (Ewing), at that time determined as *Tetranychus willamettei* McG., and *pacificus* was found on the native chokecherry and thimbleberry. In Washington, on the other hand, all material collected on apple was determined as *pacificus*.

Subsequent determinations of material from the Yakima Valley were made by McGregor in 1950, as *pacificus* or *bimaculatus*. In 1951 E. W. Baker visited the area and made numerous collections. His determinations showed the prevalent tetranychid on fruit trees to be *Tetranychus mcdanieli* McG. This change in determination suggested that *pacificus* and *mcdanieli* might actually not be distinct species. In 1953, therefore, the writer made a series of biological experiments to determine whether or not the two species were distinct. These experiments were based on the fact, long known, that infertile eggs of these mites usually hatch but produce only males. By making *pacificus* × *mcdanieli* crosses, or vice versa, it could be determined whether or not the eggs had been fertilized and thus whether or not the species were identical. This method had been used successfully by McGregor & Newcomer (1928) to prove that the European red mite and the citrus red mite were distinct species.

Authentic *pacificus* material was obtained from cotton and umbrella-tree (*Melia azedarach*) foliage at Buttonwillow, Calif.,[2] and colonized on bean plants in the laboratory at Yakima. *Mcdanieli* material was collected from apple near Yakima. The authenticity of the two species was determined by E. W. Baker and the writer.

For rearing the mites, cells made up of recessed oblong pieces of plywood, blotting paper, and Plexiglas were used, in which individual apple leaves could be kept fresh for a week. In most of the tests a single female in the deutonymphal stage was isolated in a cell with one or more males of the other species, and copulation usually occurred shortly after the

[1] Presented at the meeting of the Entomological Society of America, Los Angeles, Calif., December 7–10, 1953.

[2] Collected by Gordon L. Smith, California Agricultural Experiment Station, Shafter, Calif.

female molted. Both *pacificus* × *mcdanieli* and *mcdanieli* × *pacificus* crosses were made. No difficulty was experienced in transferring *pacificus* mites from cotton or umbrella-tree foliage to apple, or to bean and then to apple.

Ovipositing females were usually transferred to new leaves every few days in order that mites hatching from the eggs would have time to mature before the apple leaf deteriorated, and the cells were kept in a constant-temperature box at 80° to 85° F. to speed up the process. After the first 2 or 3 days the males remaining were mounted and examined microscopically to check the species. It was, of course, not possible to do this with the females. With one exception, however, which is noted later, male progeny of the females were checked and found to be the correct species. That is male progeny of *pacificus* × *mcdanieli* crosses were *mcdanieli* and vice versa.

Tables 1 and 2 give the results of these observations. Mating was observed in 9 of the 36 crosses made, and it probably took place in others. In some of the observations the male seemed to have difficulty in mating with the female, which might be expected if the species are distinct.

Of the adults from *pacificus* × *mcdanieli* crossings 99 per cent were males, and of those from *mcdanieli* × *pacificus* crossings 97 per cent. Of the eggs deposited, 68 and 44 per cent, respectively,

**Table 1.—Results of mating male pacificus with female mcdanieli mites.**

| Date of Mating | Length of Life of Female | Eggs Deposited | Progeny Maturing | | Eggs Producing Males |
|---|---|---|---|---|---|
| | | | Male | Female | |
| | *Days* | *Number* | *Number* | *Number* | *Per Cent* |
| July 28 | 14 | 78 | 33 | 0 | 42 |
| | 6 | 23 | 2 | 0 | — |
| | 12 | 47 | 35 | 0 | 75 |
| | 13[1] | 93 | 73 | 0 | 79 |
| | 6 | 13 | 11 | 0 | 85 |
| | 13 | 70 | 60 | 0 | 86 |
| 29 | 14 | 85+ | 80 | 0 | — |
| | 12[1] | 80+ | 76 | 0 | — |
| | 9 | 45 | 38 | 0 | 84 |
| | 14[1] | 59 | 34 | 8 | 58 |
| 30 | [2] | 115+ | 101 | 0 | — |
| | 7 | 28 | 28 | 0 | 100 |
| | 5 | 27 | 5 | 0 | 19 |
| | [3] | 150+ | 136 | 0 | — |
| | 7 | 30 | 14 | 0 | 47 |
| | 7 | 50 | 38 | 0 | 76 |
| | 14 | 62 | 37 | 0 | 60 |
| Aug. 29 | 8 | 31 | 2 | 0 | — |
| | 7[1] | 60 | 9 | 0 | — |
| Total or average | — | 1146+ | 812 | 8 | 68[4] |

[1] Mating observed.
[2] Two females, lived about 6 days.
[3] Three females, lived about 2 weeks.
[4] Figured from totals of crossings where exact number of eggs is known.

**Table 2.—Results of mating male mcdanieli with female pacificus mites.**

| Date of Mating | Length of Life of Female | Eggs Deposited | Progeny Maturing | | Eggs Producing Males |
|---|---|---|---|---|---|
| | | | Male | Female | |
| | *Days* | *Number* | *Number* | *Number* | *Per Cent* |
| July 28 | [2] | 40 | 11 | 8 | 27 |
| | 15 | 37 | 16 | 0 | 43 |
| | 9[1] | 20 | 10 | 0 | 50 |
| 29 | 12 | 35+ | 31 | 2 | — |
| | 7 | 19 | 2 | 0 | — |
| | 12 | 39 | 15 | 0 | 38 |
| | [3] | 44 | 15 | 0 | 34 |
| | 19[1] | 46 | 25 | 0 | 54 |
| 30 | 12 | 25+ | 21 | 0 | — |
| | 11 | 20+ | 19 | 0 | — |
| | 9 | 22 | 10 | 0 | 45 |
| Aug. 29 | 14 | 56 | 35 | 0 | 62 |
| | 13 | 17 | 5 | 0 | 29 |
| 30 | 6 | 20 | 9 | 0 | 45 |
| 31 | 18 | 49 | 24 | 0 | 49 |
| Sept. 1 | 3[1] | 15 | 12 | 0 | 80 |
| | 24[1] | 47 | 10 | 0 | 21 |
| | 6[1] | 7 | 6 | 0 | 86 |
| Total or average | — | 558+ | 276 | 10 | 44[4] |

[1] Mating observed.
[2] Three females, lived about 2 weeks.
[3] Two females, lived about 2 weeks.
[4] Figured from totals of crosses where exact number of eggs is known.

**Table 3.—Results of mating mcdanieli mites from raspberry with mcdanieli mites from apple.**

| Date of Mating | Length of Life of Female | Eggs Deposited | Progeny Maturing | | Eggs Producing Males |
|---|---|---|---|---|---|
| | | | Male | Female | |
| | *Days* | *Number* | *Number* | *Number* | *Per Cent* |
| | *Males from raspberry × females from apple* | | | | |
| May 20 | 19 | 90+ | 10 | 71 | — |
| | 19 | 69 | 40 | 16 | 58 |
| 21 | 12 | 16 | 4 | 0 | 25 |
| | 18 | 81 | 13 | 48 | 16 |
| | 18 | 124+ | 51 | 45 | — |
| | 19 | 98+ | 39 | 47 | — |
| 27 | 14 | 90+ | 26 | 64 | — |
| | 6 | 14 | 2 | 0 | 14 |
| | 13[1] | 95+ | 27 | 67 | — |
| Total or average | — | 677+ | 212 | 358 | — |
| | *Males from apple × females from raspberry* | | | | |
| May 22 | 11[1] | 30 | 17 | 0 | 57 |
| | 11 | 10 | 5 | 0 | 50 |
| 25 | 16 | 45+ | 39 | 3 | — |
| 27 | 14 | 75+ | 13 | 56 | — |
| | 13[1] | 84+ | 18 | 57 | — |
| | 13 | 34 | 10 | 13 | 29 |
| | | 278+ | 102 | 129 | — |
| Total or average | — | 953+ | — | — | 36[2] |

[1] Mating observed.
[2] Figured from totals of crossings where exact number of eggs is known.

produced males. Because of the method and lack of time to make detailed records, it is not known what percentage of the eggs hatched, but not all of them did. Also, many young were lost before reaching maturity.

For comparative purposes, crossings of *mcdanieli* from raspberry at Prosser, Washington, were made with *mcdanieli* from apple at Yakima, and the results are given in table 3. Only 39 per cent of the 801 progeny were males, and only 36 per cent of the eggs produced males.

A few females developed from three of the crosses, and females from two of them were colonized on beans. The colonies were maintained for over a month, during which time they went through one or more generations, indicating that the females were of normal vigor.

Females from a single lot in the *pacificus* × *mcdanieli* crosses (table 1) were placed on a bean plant along with males from a *mcdanieli* × *pacificus* cross. Both males and females resulted from this cross, and the males were *pacificus*. It is obvious that a mistake was made in the original crossing, for the female must have been *pacificus* and not *mcdanieli*.

Females from the first *mcdanieli* × *pacificus* cross were also placed on a bean plant, but no males were introduced. All the progeny were *pacificus* males. It is probable that, in the two *mcdanieli* × *pacificus* crosses where females resulted, at least one of the males was *pacificus*. In each case four males had been put into the cell, and not all of them were subsequently examined.

It is concluded from these studies that *pacificus* and *mcdanieli* are distinct species, in spite of the occurrence of a few female progeny. No explanation is offered for the rather rapid substitution of *mcdanieli* for *pacificus* in the Pacific Northwest.

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# Protection of Stored Shelled Corn with a Protectant Dust in Indiana

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Considerable importance is attached to the presence of insects in stored shelled corn, both from the standpoint of damage and subsequent contamination of food products. The tendency in recent years to store corn for long periods has increased the problems. Protection of stored wheat with synergized pyrethrins in several areas has been realized, and the effective use of 0.08 per cent pyrethrins and 1.1 per cent piperonyl butoxide was reported by Wilbur (1952). The U. S. Department of Agriculture (Anon. 1953) recommends this same formulation for stored wheat protection during the first storage season. Watts & Berlin (1950) reported several similar formulations which gave good to complete control of the rice weevil, *Sitophilus oryza* (L.) in wheat in short term laboratory tests. Shelled corn was treated in Alabama (Eden 1953) with 0.05 per cent pyrethrins and 0.8 per cent piperonyl butoxide at 1 pound per 10 bushels, and stored as one-bushel samples in pasteboard drums placed within a corn crib. Storage periods of 9 months showed 13.1 per cent rice weevil damage as compared with 86.1 per cent in untreated corn. Protection from infestation by other stored grain insects was not reported.

Observations in this test were made over a continuous 2-year period in bins of shelled corn in San Pierre, Indiana. The test period extended from Sept. 20, 1951 to Oct. 26, 1953, during which time the corn remained untouched.

PROCEDURE.—Four circular metal bins

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of 3000-bushel capacity were selected as a group at a PMA site. These bins were held under normal storage conditions and were filled to capacity with shelled corn. Two bins were fumigated, and the corn in them cleaned and treated while being turned. The protectant was mixed with the grain during the cleaning process. The two check bins were turned and fumigated.

The material[1] used for protection was known as Pyrenone Protectant T-483, and consisted of:

1.10% piperonyl butoxide
0.08% pyrethrins
corn cob flour carrier (direct impregnation)

This insecticide was introduced into the grain stream by an electric feeder at the rate of 75 pounds per thousand bushels of corn. In addition, each floor of the cleaned test bins was treated with 15 pounds of the material with particular attention being given to the seams and rims. After the bins were filled, the top 5 inches of corn in each bin received an additional 8-pound cap treatment.

Test samples were taken from the bins on nine different dates. Samples were handled in such a way that 90-day emergence readings were also available for each sample, giving a total observation period of 2 years, 1 month. Corn samples were taken in duplicate by standard probe as follows: horizontal top surface sample, vertical center core sample, and horizontal lower door sample. Data recorded included moisture content immediately after sampling, and numbers of immature and adult insects, alive and dead. The insect records represent one probe at each sample position.

RESULTS.—Initial samples after fumigation revealed very little active infestation in any bin, except for a considerable number of flat grain beetles on the surface of one treated bin immediately after turning and treating with protectant. A summary of the eight subsequent readings are recorded in table 1. These results indicate that over a two-year period there was highly significant difference (15.80; F** = 12.25) between the treated and untreated bins. The increased numbers of insects in the treated bins towards the end of the test period was due in large part to surface investations of the flat grain beetle. In the untreated checks, the saw-toothed grain beetle was especially abundant throughout the grain in the latter months. This same beetle was infrequent in the treated bins. Seasonal differences for all insects were highly significant.

Table 2 records the insect counts at the

[1] Material and certain equipment furnished by the Research and Development Laboratories of the U. S. Industrial Chemicals Co.

**Table 1.—Insect counts[1] at four corn bins over a two-year period, showing results of the protectant treatment. San Pierre, Indiana.**

| Months After Fumigation and Protectant Treatment | Protectant-Treated | | | | Untreated | | | |
|---|---|---|---|---|---|---|---|---|
| | Total Insects | | Living Insects | | Total Insects | | Living Insects | |
| | Bin A | Bin B | Bin A | Bin B | Bin C | Bin D | Bin C | Bin D |
| 1—(October) | 5 | 10 | 0 | 0 | 6 | 9 | 1 | 0 |
| 1—90-day emergence | 0 | 1 | 0 | 0 | 3 | 0 | 1 | 0 |
| 6—(early April) | 0 | 7 | 0 | 0 | 6 | 24 | 1 | 0 |
| 6—90-day emergence | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 0 |
| 8—(May) | 2 | 2 | 0 | 0 | 5 | 2 | 2 | 0 |
| 8—90-day emergence | 0 | 0 | 0 | 0 | 33 | 40 | 21 | 32 |
| 9.5—(July) | 21 | 3 | 12 | 0 | 74 | 37 | 67 | 35 |
| 9.5—90-day emergence | 22 | 11 | 22 | 11 | 57 | 116 | 39 | 100 |
| 11—(August) | 4 | 2 | 0 | 0 | 46 | 67 | 32 | 55 |
| 11—90-day emergence | 0 | 5 | 0 | 5 | 15 | 126 | 12 | 123 |
| 12.5—(October) | 12 | 11 | 7 | 6 | 18 | 18 | 7 | 4 |
| 12.5—90-day emergence | 3 | 4 | 0 | 3 | 0 | 11 | 0 | 11 |
| 19—(April) | 36 | 2 | 29 | 0 | 18 | 68 | 14 | 57 |
| 19—90-day emergence | 17 | 13 | 9 | 4 | 97 | 165 | 61 | 139 |
| 22—(July) | 33 | 17 | 11 | 6 | 48 | 146 | 15 | 90 |
| 22—90-day emergence | 22 | 82 | 9 | 77 | 52 | 495 | 48 | 478 |
| Total bins A+B; C+D | 347 | | 211 | | 1,805 | | 1,447 | |

[1] Insects per three probes per bin.

**Table 2.—Total number of insects[1] taken at surface, center, and door locations in four corn bins over a two-year period.**

| Location of Samples | Protectant Treated | | | | Untreated | | | |
|---|---|---|---|---|---|---|---|---|
| | Total Insects | | Living Insects | | Total Insects | | Living Insects | |
| | Bin A | Bin B | Bin A | Bin B | Bin C | Bin D | Bin C | Bin D |
| Surface | 138 | 118 | 90 | 87 | 219 | 285 | 182 | 239 |
| Total | *256* | | *177* | | *504* | | *421* | |
| Center probe | 20 | 44 | 4 | 24 | 111 | 469 | 60 | 409 |
| Total | *64* | | *28* | | *580* | | *469* | |
| Door | 19 | 8 | 6 | 0 | 151 | 570 | 81 | 476 |
| Total | *27* | | *6* | | *721* | | *557* | |

[1] From a total of eight probes per location.

three different probe locations. As might be expected in bins treated with the pyrethrum base protectant, the greatest number of insects was from surface samples. Infestations were progressively less in number, the lower the location within the bin. It is possible that the floor treatment contributed to this occurrence, but the pyrethrum was unquestionably effective for a longer period well below the surface. In the untreated bins, there is no statistical difference between samples taken at various levels.

During the two-year period, the five most prevalent insects were, in descending numerical order: the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.); flat grain beetle, *Laemophloeus pusillus* (Schönh.); red flour beetle, *Tribolium castaneum* (Hbst.); Indian meal moth, *Plodia interpunctella* (Hbn.); and foreign grain beetle, *Ahasverus advena* (Waltl.). Other less prevalent insects which occurred in the four bins in total numbers of 24 or fewer specimens per species were, in descending numerical order: larger black flour beetle, *Cynaeus angustus* Lec.; hairy fungus beetle, *Typhaea stercorea* (L.); lesser mealworm, *Alphitobius diaperinus* (Panz.); confused flour beetle, *Tribolium confusum* Duv.; yellow mealworm, *Tenebrio molitor* L.; and granary weevil, *Sitophilus granarius* (L.) The rice and granary weevils are not numerous in northern Indiana in stored corn and only one specimen, a granary weevil, appeared in these samples. The saw-toothed grain beetle contributed greatly to the larger numbers towards the end of the test period, but the flat grain beetle, second in abundance, occurred most frequently in both the treated and untreated bins. The Indian meal moth made its first appearance in the untreated bins 8 months after fumigation and became quite abundant on the surface. In the treated corn, this moth did not appear for 14 months and occurred only in small numbers. It is noted that the same two insects, the saw-toothed grain beetle and flat grain beetle, which ranked most abundant in these bins are considered the most abundant in the North Central States as reported by Cotton *et al.* (1953).

The moisture content of the corn during the test period ranged from 11.4 to 19.7 per cent with a mean of 14.1. There was no statistical difference between bins. The corn was sold following the last sampling; it graded lowest in the check bins (Sample).

Summary.—Two standard metal bins containing corn treated with a piperonyl butoxide- pyrethrins protectant dust were compared with two untreated bins. Although the number of bins was small, they were representative of the corn storage in the area of the test, and the data were analyzed statistically. The test showed that a highly significant difference occurred between treated and untreated corn. The corn below the surface layer in the treated bins remained free of heavy infestation during the two-year period of the test. The surface became only moderately infested in the latter months of the observations. The indications are that fumigated or clean shelled corn can be protected for a two-year period under normal conditions of storage in northern Indiana by the use of this grain protectant.

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# Some Phosphorus Compounds as Systemic Insecticides Against Cattle Grubs

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The possibility of controlling bloodsucking parasites by feeding chemicals to the host animal has been an intriguing challenge to entomologists and parasitologists during the last three decades. Bishopp *et al.* (1926) reported unsuccessful attempts to control various ectoparasites on laboratory animals. Parman (1928) reported failure of a large number of chemicals to control ectoparasites of poultry. Knipling (1938) and Bruce (1939) were successful in preventing the development of the larvae of the horn fly, *Siphona irritans* (L.), by feeding phenothiazine to cattle. Lindquist *et al.* (1944) showed that the blood of rabbits given oral doses of pyrethrum and DDT was toxic to bed bugs, *Cimex lectularius* L., and stable flies, *Stomoxys calcitrans* (L.). de Meillen (1946) reported that several bloodsucking insects were affected when fed on a rabbit that had been given gamma benzene hexachloride.

Administering insecticides by subcutaneous injection began with Knipling *et al.* (1948), who so tested a number of insecticides against several bloodsucking insects. Barrett and Wells (1948), using white mice in which first-instar larvae of the cattle grub had been implanted, showed that certain dyes would reach the larvae after subcutaneous injection but found none that were toxic to the larvae. de Toledo and Saur (1950) reported promising results with some chlorinated hydrocarbon insecticides administered orally or subcutaneously for the control of *Dermatobia hominis* (L., Jr.) in South America. McGregor and Radeleff (data not yet published) during 1952 and 1953 demonstrated complete control of the cattle grubs *Hypoderma lineatum* (De Vill.) and *bovis* (L.) and other ectoparasites with subcutaneous injections of lindane, dieldrin, or aldrin in peanut oil. Similar results on biting flies were obtained by Lindquist *et al.* (1953). Because of the residues found in the fat of cattle so treated the method was not satisfactory.

The search has continued for materials toxic to ectoparasites, nontoxic to the host, and without a questionable residue in the tissues or products of the treated animals. These goals have not been attained, but results with some organic phosphorus compounds have widened the field of investigation and have thus increased the hope of success. Preliminary studies with a few of these phosphorus insecticides are reported herein.

Methods and Materials.—Screening of candidate materials was done with the guinea pig as the host animal and the screw-worm, *Callitroga hominivorax* (Coqu.), as the test insect. The materials were administered subcutaneously in solutions in peanut oil or Tween 20 (polyoxyethylene sorbitan monolaurate). Treatments were given to guinea pigs infested with 1-day-old screw-worm larvae, and the mortality of the larvae was recorded after 24 and 48 hours. The duration of insecticidal effect was determined by implanting newly hatched larvae from the laboratory colony in the wound twice a week until they were able to establish and to grow normally.

The chemicals showing effectiveness in

[1] Agr. Res. Serv., U.S.D.A.

**Table 1.—Effectiveness of subcutaneous injections of Diazinon against the common cattle grub.**

| Dosage (mg./kg.) | Grubs at Treatment | | Grubs Encysting After Treatment | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 Week | | 2 Weeks | | 3 Weeks | | 4 Weeks | | 5 Weeks | | 6 Weeks | |
| | Found | Died | Found | Died | Found | Died | Found | Died | Found | Died | Found | Died | Found | Died |
| 5 | 53 | 53 | 7 | 7 | 0 | — | 0 | — | 3 | 1 | 5 | 1 | 0 | — |
| 10 | 28 | 28 | 5 | 5 | 7 | 7 | 10 | 8 | 0 | — | 0 | — | 0 | — |
| | 14 | 14 | 11 | 11 | 6 | 6 | 21 | 15 | 2 | 1 | 1 | 0 | 0 | — |
| 25 | 8 | 8 | 6 | 6 | 9 | 9 | 15 | 15 | 28 | 17 | 7 | 0 | 3 | 0 |
| | 21 | 21 | 22 | 22 | 4 | 4 | 5 | 5 | 8 | 3 | 3 | 0 | 0 | 0 |
| 50 | 21 | 21 | 5 | 5 | 8 | 8 | 10 | 10 | 11 | 4 | 6 | 1 | 1 | 0 |
| | 14 | 14 | 5 | 5 | 0 | — | 1 | 1 | 6 | 0 | 11 | 2 | 0 | — |
| | 21 | 21 | 0 | — | 0 | — | 0 | — | 8 | 0 | 13 | 0 | 0 | — |

these screening tests were then administered to cattle infested with cattle grubs. Diazinon (0,0-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) thiophosphate) was administered subcutaneously in a 5-per cent solution in refined peanut oil. The remaining compounds were administered orally—chlorthion (0-(3-chloro-4-nitrophenyl) 0,0-dimethyl thiophosphate) in an emulsion, Bayer 21/199 (3-chloro-4-methylumbelliferone 0,0-diethyl thiophosphate) in a suspension, and Bayer L 13/59 (0,0-dimethyl 2,2,2-trichloro-1-hydroxy-ethylphosphonate) in an aqueous solution. Diazinon was also administered orally in an emulsion.

Records were kept of the appearance and disposition of each cattle grub at 2-day intervals. A single treatment was administered when grubs had made their appearance in the backs of the cattle.

RESULTS.—The results obtained by subcutaneous injection of Diazinon in peanut oil are summarized in table 1. All dosages (5 to 50 mg./kg.) gave complete kill of the grubs present at the time of treatment and of all those appearing for the next 2 weeks. The 10-mg. dosage was not completely effective at 3 weeks, and none of the dosages were effective 4 weeks after injection. The 5-mg. dosage could not be properly evaluated after the first week because no grubs appeared during the second and third weeks.

The results obtained from oral administration of certain insecticides are summarized in table 2. Diazinon at 10 and 25 mg./kg. gave almost complete kill of the grubs present at time of treatment. The lower dosage was completely effective against new grubs for 1 week but less effective the second week. No new grubs appeared after treatment at the higher dosage.

Compound L 13/59 gave excellent kill of the grubs present at treatment. At the highest dosage complete kill of new grubs occurred for 2 weeks after treatment, partial kill at 3 weeks, and no kill at 4 weeks. With each of the lower dosages no new grubs appeared during the 4-week observation period, probably an indication that grubs were not present rather than killed by the treatment.

**Table 2.—Effectiveness of oral treatments with phosphorus insecticides against the common cattle grub.**

| Insecticide | Dosage (mg./kg.) | Grubs at Treatment | | Grubs Encysting After Treatment | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 Week | | 2 Weeks | | 3 Weeks | | 4 Weeks | |
| | | Found | Died | Found | Died | Found | Died | Found | Died | Found | Died |
| Compound L 13/59 | 100 | 33 | 33 | 7 | 7 | 4 | 4 | 5 | 2 | 8 | 0 |
| | 50 | 13 | 11[1] | 0 | — | 0 | — | 0 | — | 0 | — |
| | 25 | 33 | 28[1] | 0 | — | 0 | — | 0 | — | 0 | — |
| Chlorthion | 50 | 38 | 26[1] | 0 | — | 0 | — | 6 | 0 | 5 | 0 |
| Compound 21/199 | 25 | 56 | 0 | 9 | 0 | 0 | — | 0 | — | 0 | — |
| Diazinon | 25 | 73 | 68[1] | 0 | — | 0 | — | 0 | — | 0 | — |
| | 10 | 8 | 8 | 9 | 9 | 6 | 4 | 2 | 0 | 2 | 0 |

[1] Surviving grubs left cysts soon after treatment.

Chlorthion at 50 mg./kg. killed approximately 66 per cent of the grubs present at time of treatment. During the first and second weeks no grubs appeared, and at 3 weeks grubs appeared but were not killed.

Compound 21/199 at 25 mg./kg. was completely ineffective at the time of treatment and during the 4-week observation period.

Few, if any, grubs were killed before reaching the back, since new grubs usually appeared 4 to 6 weeks after treatment.

Because each of the oral dosages was given to a single animal, there is no opportunity to check the results for consistency.

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# A Survey on DDT-Accumulation in Soils in Relation to Different Crops[1]

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Since 1947, when the application of DDT became a standard practice for insect control in orchards, field and vegetable crops, the fear of accumulating large deposits of this toxicant in soils has been a source of concern to federal and state investigators, farmers, and commercial manufacturers. The ultimate fate of DDT applied to growing crops is still a matter of conjecture. Will it decompose and disappear from the soils, or will its deposits from sprays and dusts continue to increase from year to year and eventually reach quantities harmful to plant growth?

This problem has become more challenging since recent results from several investigations indicate that not all plants are tolerant to DDT. Several crops show distinct injury and growth retardation either from spray applications, Dudley (1947), Gould (1951), Weigel (1951), and Wyle (1952), or as a result of incorporating DDT directly into the soil, Fleming (1947), (1948), Foster (1951), and Thurston (1953). While certain crops commonly treated with DDT appear highly tolerant to it, such as many grains, orchard trees, corn, and potatoes, other crops commonly grown in rotation with them are highly sensitive, such as Rosen and Abruzzi rye, tomatoes, squash, and snap beans.

The possibility of accumulating DDT in soils from spray practices is of greater significance in orchards and with crops where the green plants are turned under and incorporated in the soil after each harvest, as is generally practiced with potatoes and sweet corn. In apple orchards, for instance, where four or more

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, Rutgers University, the State University of New Jersey, Department of Entomology, New Brunswick.

sprays may be applied each season, the DDT residues may amount to 30 to 50 pounds per acre annually. Of course, not all of this quantity is expected to reach the soil. Part of it will decompose by sunlight while still on the foliage or on the soil surface, Lindquist *et al.* (1946), Chisholm *et al.* (1949), Kirk (1952), and Ginsburg (1953). A portion of it may be washed out by heavy showers. Some of the DDT will decompose in the soil while in contact with certain catalytic agents, such as oxides of iron: Fleck & Haller (1945), Fleck (1948), Gunther & Tow (1946), and Downs *et al.* (1951).

A considerable amount of investigational work has already been carried out on the persistence of DDT in different soils. Smith (1948) incorporated DDT in acid and alkaline soils ranging in pH from 5.8 to 8.0. After 18 months of exposure outdoors, or by controlled leaching in the laboratory, about 95 per cent of the original amount of the DDT has been recovered in both ranges of soil. Ackley *et al.* (1950) have analyzed soils from apple orchards in the Wenatchee and Yakima areas in Washington, sprayed for several years with DDT, and found variations of from 29 to 81 p.p.m. of DDT in the upper 4 inches of soil. Westlake (1950) analyzed soils from six apple orchards after 3 years of spraying and reported variations from 46 to 91 pounds per acre. Fleming *et al.* (1951), after recovering about 30 per cent of the total DDT incorporated in field plots about 6 years after treatment, concludes that DDT in soil undergoes a slow rate of decomposition. Foster (1951), reports that a soil from a peach orchard sprayed annually with 25 pounds of DDT per acre during 1946-49 contained at 3 to 4 inch depth 11 and 127 p.p.m. DDT between and under trees, respectively. Fleming & Maines (1953) incorporated 25 pounds of DDT per acre in 84 mineral soils and in one muck soil and subjected them to weathering. At the end of 8 years, about 44 per cent of the original DDT remained in the soils, being most persistent in sand and least in muck. The pH within the range of 4 to 7.5 seemed to have no effect.

In general, the results previously reported seem to indicate that DDT does not readily decompose in most of the cultivated soils and may, after repeated annual applications, remain in sufficiently large quantities to interfere with the growth of certain crops.

The purpose of this investigation is two-fold: First, to determine the quantities of DDT that have already accumulated in New Jersey soils from spray and dust applications on different crops, and Second, to conduct periodic or annual analyses of the soils in order to secure information on the rate at which DDT deposits continue to increase as a result of successive annual spray applications.

MATERIALS AND METHODS.—Soils from 12 apple orchards, 8 potato farms, 10 sweet corn fields, and 1 cranberry bog were analyzed for DDT in 1953. The apple orchards were selected in the major apple growing regions in the state. Each orchard received annually, since 1947, three to four sprays of DDT, 50 per cent W.P. at 1 to 2 pounds per 100 gallons, usually following the recommendations in New Jersey. The soil types encountered were: Loam—3; Collington sandy loam—4; and Sassafras sandy loam—5. Speed sprayers were employed in all orchards. Most of the orchards were cultivated regularly to a depth of 3 to 5 inches, while some were kept in sod and only occasionally cultivated. Representative sections in each orchard were selected in consultation with the grower. Samples were collected under the spread of branches, approximately 4 to 6 feet (depending on the size of the tree) from the main tree-trunk and in rows between trees at three depths, —0 to 4 in., 4 to 8 in. and 8 to 12 in. A standard LaMotte soil sampling tube approximately 1 inch in diameter was used. A sample consisted of 4 to 6 cores around each tree, from about 10 trees per section. The samples were collected in paper bags, and the heavy clumps were broken up and allowed to dry in the laboratory. The air-dried soil was then thoroughly mixed and stored for chemical analyses. By a similar procedure, soil samples from the other three crops were collected.

The potato farms received several applications of sprays or dusts of various DDT formulations each season since 1946. In each of the selected farms, potatoes were grown annually and cultivated to a depth of about 9 inches. The vines were plowed under after harvest. The soils were sampled at depths of 0 to 9 and 9 to 12 inches.

The corn fields received several applications of sprays and dusts each season since 1947. Sweet corn was grown annually, and the stubble was plowed under to a depth of 9 to 10 inches. In four farms the soils were sampled at depths of 0 to 4, 4 to 8, and 8 to 12 inches, whereas in the other six farms, samples were collected only at two depths namely, 0 to 9 and 9 to 12 inches. Eight of the soils were sandy loams and two were clays.

One cranberry bog was analyzed at depths of 0 to 4, 4 to 8, and 8 to 12 inches. The cranberries in this bog received an average of two dusts and two sprays each season since 1947. At the time of sampling, June 11, 1953,[2] the records showed 13 dustings and 12 sprays The total amount of actual DDT applied on this bog during the entire period was about 85 pounds per acre.

The DDT-analyses were made by the colorimetric method of Schechter *et al.* (1945) as modified by Wichman *et al.* (1946), Downing & Norton (1951), and Pontoriero & Ginsburg (1953). Three hundred gm. of soil were extracted with 300 ml. of benzene by shaking for about 30 minutes. The filtrates were decolorized by shaking for 5 to 10 minutes, as required, with about 5 gm. of a mixture containing four parts filter cell and two

[2] These samples were obtained through the efforts of Dr. O. Starnes.

**Table 1.—DDT recovered from soils in apple orchards sprayed during 1947–1952.**

| Orchard No. | Location and Description of Orchard | Part of Orchard | Soil Depth, Inches | DDT-Recovered P.P.M. | DDT-Recovered Pounds/Acre | |
|---|---|---|---|---|---|---|
| 1 | New Brunswick | Under | 0–4 | 63.7 | 76.5 | |
| | Nixon loam | trees | 4–8 | 1.4 | 1.6 | |
| | Medium size trees of different varieties, spaced 24×20 ft. Occasionally cultivated to a depth of 3 to 4 inches. | | 8–12 | 0.4 | 0.5 | |
| | | | | | | 78.7 |
| | | Between | 0–4 | 29.8 | 35.8 | |
| | | trees | 4–8 | 3.4 | 4.0 | |
| | | | 8–12 | 0.1 | 0.1 | |
| | | | | | | 39.9 |
| 2 | South River | Under | 0–4 | 73.0 | 87.6 | |
| | Sassafras sandy loam | trees | 4–8 | 19.8 | 23.7 | |
| | Large Rome trees spaced 28×32 ft. Cultivation 4 to 5 inches deep. | | 8–12 | 1.9 | 2.3 | |
| | 20–25 spray gal. per tree. | | | | | 113.6 |
| | | Between | 0–4 | 39.2 | 47.0 | |
| | | trees | 4–8 | 9.3 | 11.2 | |
| | | | 8–12 | 0.0 | 0.0 | |
| | | | | | | 58.2 |
| 3 | Penn's Neck | Under | 0–4 | 25.3 | 30.4 | |
| | Sassafras loam | trees | 4–8 | 3.0 | 3.6 | |
| | Large Rome trees spaced 40×40 ft. Soil kept in sod, rarely cultivated, no cover crop. | | | | | 34.0 |
| | 12–14 spray gal. per tree. | Between trees | 0–4 | 16.0 | 19.24 | |
| 4 | Same as No. 3, but the trees are spaced 30×30 ft. | Under | 0–4 | 37.5 | 45.0 | |
| | | trees | 4–8 | 6.1 | 7.3 | |
| | 12–14 spray gal. per tree. | | | | | 52.3 |
| | | Between trees | 0–4 | 13.4 | 16.0 | |
| 5 | Cranbury | Under | 0–4 | 55.1 | 66.0 | |
| | Sassafras sandy loam | trees | 4–8 | 3.9 | 4.7 | |
| | Several varieties planted in 1932. Spaced 30×36 ft. Cultivation 3 to 4 inches deep. | | | | | 70.0 |
| | Rye cover crop. Straw-mulch. | Between | 0–4 | 21.2 | 25.4 | |
| | About 20 spray gal. per tree. | trees | 4–8 | 1.1 | 1.3 | |
| | | | | | | 26.7 |

| Orchard No. | Location and Description of Orchard | Part of Orchard | Soil Depth, Inches | DDT-Recovered P.P.M. | DDT-Recovered Pounds/Acre | |
|---|---|---|---|---|---|---|
| 6 | Tennent Square, Freehold<br>Loam<br>Several varieties planted in 1930. Spaced 40×36 ft. Cultivation 3 to 5 inches. Hay mulch. Vetch cover crop.<br>About 17 spray gal. per tree. | Under trees | 0–4 | 44.3 | 53.2 | |
| | | | 4–8 | 4.6 | 5.5 | |
| | | | 8–12 | 2.6 | 3.2 | |
| | | | | | | 61.8 |
| | | Between trees | 0–4 | 21.2 | 25.4 | |
| | | | 4–8 | 6.9 | 8.2 | |
| | | | 8–12 | 3.7 | 4.5 | |
| | | | | | | 38.2 |
| 7 | Freehold<br>Collington sandy loam<br>Rome & McIntosh planted in 1928. Spaced 36×36 ft. Cultivation 3 to 4 inches. Vetch cover crop or left in sod. | Under trees | 0–4 | 31.5 | 37.8 | |
| | | | 4–8 | 7.5 | 9.0 | |
| | | | | | | 46.8 |
| | | Between trees | 0–4 | 38.6 | 45.3 | |
| | | | 4–8 | 13.5 | 16.2 | |
| | | | | | | 61.5 |
| 8 | Colts Neck<br>Collington sandy loam<br>Rome & McIntosh planted 1928. Spaced 36×36 ft. Cultivation 3 to 4 inches deep or left in sod. No cover crop. | Under trees | 0–4 | 54.7 | 65.6 | |
| | | | 4–8 | 14.9 | 18.8 | |
| | | | | | | 84.5 |
| | | Between trees | 0–4 | 31.3 | 37.6 | |
| | | | 4–8 | 1.0 | 1.2 | |
| | | | | | | 38.7 |
| 9 | Marlton<br>Collington loam<br>Red Rome planted 1912. Spaced 40×40 ft. No cultivation. No cover crop. | Under trees | 0–4 | 43.1 | 51.7 | |
| | | | 4–8 | 5.1 | 6.1 | |
| | | | 8–12 | 5.8 | 6.9 | |
| | | | | | | 64.7 |
| | | Between trees | 0–4 | 15.8 | 18.9 | |
| 10 | Vincentown<br>Sassafras sandy loam<br>Red Rome planted in 1919. Spaced 40×32 ft. Cultivation 4 to 5 inches deep. No cover crop. | Under trees | 0–4 | 31.5 | 37.8 | |
| | | | 4–8 | 8.5 | 10.1 | |
| | | | | | | 47.9 |
| | | Between trees | 0–4 | 21.1 | 25.4 | |
| | | | 4–8 | 8.8 | 10.5 | |
| | | | | | | 35.9 |
| 11 | Marlton Pike<br>Collington fine sandy loam<br>Rome trees spaced about 24×34 ft., cultivated. No cover crop. | Under trees | 0–4 | 34.7 | 41.7 | |
| | | | 4–8 | 25.5 | 30.6 | |
| | | | | | | 72.3 |
| | | Between trees | 0–4 | 18.9 | 22.6 | |
| | | | 4–8 | 12.5 | 15.0 | |
| | | | | | | 37.6 |
| 12 | Masonville<br>Sassafras loamy sand<br>Trees 40 years old, spaced 40×40 ft., were removed in 1951. The soil was then plowed to a depth of 9 inches and tomatoes planted in 1952. Poor growth observed in places where the trees stood. | In places where trees stood | 0–9 | 13.9 | 37.50 | |
| | | | 9–12 | 7.6 | 6.82 | |
| | | | | | | 44.3 |
| | | Between trees | 0–9 | 9.9 | 26.7 | |

**Table 2.—Average DDT in Orchard Soils at Different Depths.**

| Soil Depth (Inches) | Pounds of DDT Per Acre | | | |
|---|---|---|---|---|
| | Under Trees | | Between Trees | |
| | Min. | Max. | Min. | Max. |
| 0–4 | 37.7 | 87.6 | 26.7 | 61.5 |
| 4–8 | 1.6 | 30.6 | 1.3 | 15.0 |
| 8–12 | 0.5 | 6.9 | 0.0 | 4.5 |
| 0–12 (total) | 35 | 113 | 26 | 61 |

parts *Nuchar*. Aliquots of the clear filtrates were used for analyses. The photometric densities of *p,p'*-DDT were measured on the Fischer electrophotometer at a wave length of 580 $m_u$ (Filter #58) and compared with a standard curve of *p,p'*-DDT, similarly developed, from technical DDT.[3] The average results of the chemical analyses as well as a brief description of each soil and treatment are presented in six tables.

RESULTS.—*DDT in Apple Orchard Soils.*—The results, presented in table 1, brought out the following information. In 11 of the 12 orchards tested, larger quantities of DDT have accumulated in soils under the spread of branches than in rows between trees. Only in one orchard (No. 7), the results were reversed. In all orchards, most of the DDT was found in the upper 4 inches of soil, corresponding to the average depth of cul-

[3] Mr. S. Buckser assisted in the chemical analyses.

**Table 3.—DDT deposits in soils from potato crops, sprayed during 1946–52.**

| Farm No. | Location and DDT Applications | Soil Depth (Inches) | DDT-Recovered | |
|---|---|---|---|---|
| | | | P.P.M. | Pounds/Acre |
| 1 | Salem. Sandy loam. 25% DDT emulsion, 1 quart per 100 gal. (0.5 lb. DDT). From 5 to 7 sprays were applied each season during 1947–52, cultivated to 9–10-inch depth. | 0–9<br>9–12 | 1.5<br>0.6 | 4.0<br>0.5<br>4.5 |
| 2 | Elmer[1]<br>Sassafras loamy course sand. | 0–9<br>9–12 | 1.7<br>0.2 | 4.5<br>0.2<br>4.7 |
| 3 | Elmer[1]<br>Sassafras loamy course sand. | 0–9<br>9–12 | 1.0<br>1.2 | 2.7<br>1.1<br>3.8 |
| 4 | Salem[1]<br>Sandy loam | 0–9<br>9–12 | 1.5<br>1.1 | 4.0<br>1.0<br>5.0 |
| 5 | Freehold[1]<br>Monmouth loam | 0–9<br>9–12 | 1.8<br>0.4 | 4.5<br>0.4<br>4.9 |
| 6 | New Brunswick. Sassafras sandy loam. 50% W.P., 2 lbs./100 gal. Sprayed 125 gal. per acre, 7–8 times each season during 1946–52. Cultivation to 9-inch depth. | 0–9<br>9–12 | 5.1<br>1.0 | 13.8<br>0.9<br>14.7 |
| 7 | Cranbury. Sassafras sandy loan. As No. 6, but applied only during 1946–51. | 0–9<br>9–12 | 2.9<br>0.4 | 7.8<br>0.4<br>8.2 |
| 8 | Freehold. Sassafras sandy loam. Dusted with 3% DDT by airplane during 1946–50. Sprayed as in No. 6 during 1951–52. | 0–9<br>9–12 | 3.4<br>1.7 | 9.2<br>1.5<br>10.7 |

[1] Same treatments and cultivation as Farm No. 1.

Table 4.—DDT found in soils from corn crops sprayed and dusted during 1947–52.

| Farm No. | Location and DDT Applications | Soil Depth (Inches) | DDT-Recovered P.P.M. | DDT-Recovered Pounds/Acre |
|---|---|---|---|---|
| 11 | Bridgeboro. Sandy loam. 5 applications annually of 1–2 lbs. DDT/acre. Dusts were used in 1948–49–50 and sprays in 1951 and 1952. | 0–4<br>4–8<br>8–12 | 4.2<br>3.3<br>2.2 | 5.0<br>4.0<br>2.6<br>11.6 |
| 12 | Salem. Dusted 5 times each season with 1–2 lbs. DDT/acre during 1948–52. | 0–4<br>4–8<br>8–12 | 4.0<br>3.3<br>2.6 | 4.8<br>4.0<br>3.2<br>12.0 |
| 13 | Same as No. 12. | 0–4<br>4–8<br>8–12 | 2.0<br>2.0<br>1.0 | 2.3<br>2.3<br>1.2<br>5.8 |
| 14 | Same as No. 12. | 0–4<br>4–8<br>8–12 | 2.5<br>1.8<br>1.3 | 3.0<br>2.2<br>1.5<br>6.7 |
| 15 | Marlton. Evesboro sandy loam. 1948–49. 3% dust, 35 lbs./acre, 4 applications yearly. 1950–52—5% dust, 35 lbs. per acre, 4 applications yearly. 1951–52—4 extra applications of 5% dust on broccoli. | 0–9<br>9–12 | 3.4<br>1.0 | 9.2<br>0.9<br>10.1 |
| 16 | Burlington. Sassafras sandy loam. 1947–48—3% dust, 50 lbs./acre, 3 or more applications per year. 1949–52—5% dust, 50 lbs./acre, 4 applications annually. | 0–9<br>9–12 | 6.5<br>1.9 | 17.4<br>1.7<br>19.1 |
| 17 | Florence. Sassafras sandy loam. 1947–49—3% dust, 50 lbs./acre. 1950–51—5% dust, 50 lbs./acre, 5 applications per year. 1952—2 sprays of 2 lbs. 50% W.P. per 100 gals. per acre. | 0–9<br>9–12 | 6.5<br>0.7 | 16.4<br>0.6<br>17.0 |
| 18 | Marlton. Collington sandy loam. 1946–47—3% dust, 50 lbs./acre, 4 applications each year. 1948–52—5% dust, 50 lbs. per acre, 5 applications annually. 1949—no treatment. | 0–9<br>9–12 | 6.3<br>0.5 | 17.0<br>0.5<br>17.5 |
| 19 | Springfield. Heavy clay. 1949–52—5% dust, appl'd 5–6 times each year at 35 lbs./acre. | 0–9<br>9–12 | 2.7<br>1.0 | 7.3<br>0.9<br>8.2 |
| 20 | Closter. Medium clay loam. 1951—5 sprays of DDT emuls. at 1.5 lbs./acre. 1952—3 sprays of the same. Total=12 lbs. DDT/acre. | 0–9<br>9–12 | 2.4<br>0.4 | 6.5<br>0.4<br>6.9 |

tivation. Small quantities were recovered in 4 to 8 inches depths and still smaller amounts at the 8 to 12 inches depths. The average total DDT recovered from all depths (Table 2) in any single orchard, measured in pounds per acre, varied from 35 to 113 under trees and from 26 to 61 between trees.

*DDT in Potato Soils.*—The total amount of DDT recovered in this group of soils (Table 3) varied from a minimum of 3.8 to a maximum of 14.7 pounds per acre. Practically all of the DDT was present in the 0 to 9 inch layer of soil or plow depth, and very little at the 9 to 12-inch layer. Apparently DDT does not pene-

trate vertically downward, unless plowed in or other wise mechanically mixed. It should be pointed out here that the lowest quantities of DDT deposits were recovered in the five soils where sprays of DDT emulsion were applied, giving a narrow range of 3.8 to 5 pounds per acre. On the other hand, the highest amount (14.7 pounds) was found in soil No. 6 where DDT-W.P. sprays were used. In the emulsion formula only 0.5 pound of actual DDT per 100 gal. was used as compared with 1 pound of actual DDT in W.P. form.

*DDT in Corn Soils.*—Rather large variations (Table 4) were encountered in this group of soils, ranging from 5.8 to 19.1 pounds of DDT per acre. As in the potato soils, the greatest amount of DDT accumulated within the plow depth layer of 0 to 9 inchs. This fact is brought out even more clearly when the soil analyses from farm Nos. 11, 12, 13 and 14, where three depths were sampled, are examined. The middle layer of 4 to 8 inchs yielded almost as much DDT as the surface layer of 0 to 4 inches, whereas the lowest layer of 8 to 12 inches contained much less DDT than the upper layers, but considerably more than the 9 to 12-inch depths in the soils from farm Nos. 15 to 20 inclusive. Evidently the layer of soil at 8 to 9 inch, which was still within the plow depth, is responsible for the higher amounts of DDT recovered from the 8 to 12 inch depths in the first four soils, as compared with the 9 to 12-inch depths in the other six soils. In this respect, no differences were apparent between the two clay soils, Nos. 19 and 20, and the four sandy loam soils, Nos. 15, 16, 17, and 18. In each case, regardless of soil type, practically all of DDT remained within the plow depth layer, again indicating no vertical downward movement of DDT.

*DDT in Cranberry Bog Soil.*—The results show a total of 34.5 pounds of DDT recovered out of an approximate gross total of 85 pounds applied since 1947. Applications of DDT were started in this bog in 1947 and continued to date of sampling in 1953. Each year about two applications of dust and two of sprays were applied. A total of 13 applications of 5 to 1 per cent DDT at 50 pounds per acre and 11 applications of 50 per cent wettable powder at 5 pounds per acre and one application of 50 per cent wettable powder at 8 pounds per acre were made. As in the other three groups of soil, most of the DDT (32 pounds) was located in the upper 4 inches, little (2.5 pounds) at 4 to 8 inches, and none at 8 to 12 inches. Even in this light, fluffy type of soil, the DDT did not penetrate downward to any appreciable extent below the cultivation depth of 4 inches.

**Table 5.—Average amounts of DDT in soils from different crops.**

| Crops | Pounds of DDT per Acre | | |
|---|---|---|---|
| | Min. | Max. | Avg. total of all soils |
| Potatoes | 4 | 15 | 7 |
| Corn | 6 | 19 | 11 |
| Cranberries | — | 34 | — |
| Apple Orchards | | | |
| Under trees | 35 | 113 | 54 |
| Between trees | 26 | 61 | 35 |

DISCUSSION.—The variations in the quantities of DDT recovered within each group of soil may be ascribed to one or more of the following factors: DDT formulations employed; number of sprays or dusts applied per season; methods of application; total amount of DDT applied per acre; soil topography, and climatic conditions. In orchard soils, the number of trees per acre, size of trees, and the gallonage applied per tree with each spraying are also contributing factors. In the apple orchards tested, the amounts applied per tree with each spray varied from 12 gallons in orchard No. 3, where the DDT deposits in the soil were comparatively low, to about 25 gallons in orchard No. 2, where high DDT deposits were found. Apparently the type of soil has not played any significant part in the DDT accumulation.

For the sake of comparison, the overall average total DDT found per acre of soil from different crops are summarized in table 5. The lowest DDT deposits, 7 pounds per acre, were present in potato soils. This was followed by 11 pounds in corn soils; 34 pounds in the cranberry bog, and 54 pounds in soils from apple orchards.

SUMMARY AND CONCLUSIONS.—A study was made on the accumulation of DDT deposits in soils from 12 apple orchards, 10 corn fields, 8 potato farms, and 1 cranberry bog as a result of commercial spray

and dust applications for insect control during the last 6 years. Samples of soils, collected at different depths, were analyzed for DDT and brought out the following:

In soils from apple orchards the DDT ranged, in pounds per acre, from 35 to 113 under trees and from 26 to 61 between trees. Most of the DDT was found in the upper 4 inches of soil, corresponding to the average depth of cultivation, small quantities in 4 to 8 inch-depths, and low amounts at 8 to 12-inch depths.

The cranberry bog contained a total of 34.5 pounds of DDT per acre, of which 32 pounds were present in the upper 4 inches of soil.

In corn soils, the total DDT ranged from 5.8 to 19, or an average of 11 pounds per acre.

The lowest deposits of DDT were found in potato soils ranging from about 4 to 15, or an average of 7 pounds per acre.

Practically all of the DDT recovered in both potato and corn soils was located at 0 to 9-inch layers, corresponding to the average plow depth.

Generally the results indicate that DDT residues do not penetrate vertically downward below the plow and cultivation depths.

The soil type in this investigation, ranging from loamy sand to heavy clay, did not play any significant role in the amount of DDT retained from the spray and dust residues.

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# Cabbage Maggot Control in Late Cabbage[1]

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Cabbage maggot control in plantings of late cabbage in western New York is at present conducted in field seedbeds during late April and the seedlings are transplanted into the field during June and early July. Control of the cabbage maggot is only necessary during the seedbed stage with this type of culture, and the methods recommended by Glasgow (1925) are still in general usuage. These are: (1) covering the seedbed with cheesecloth to prevent oviposition by the adults; (2) treating the seedlings with drenches of either corrosive sublimate or calomel. These control measures are neither practical nor economical except where plants are concentrated in a small area such as a seedbed and even here could be considerably more effective. Lack of an economical and effective method of control for the cabbage maggot in the field has been one of the main limiting factors to the seeding of late cabbage directly in the field in which it is to mature. This work was undertaken to develop such a control method and also a better control method for use in the seedbed.

1950 Experiment.—Four insecticides —aldrin, chlordane, and dieldrin, each at 4 and 8 pounds of toxicant per acre, and heptachlor at 2 and 6 pounds per acre— were tested as soil insecticides for the control of the cabbage maggot in a field seeding of cabbage. Plots were treated on April 26 by broadcast applications of the insecticides, diluted with pyrophyllite and applied at the rate of 500 pounds of dilute dust per acre, to the top of the soil with a hand fertilizer spreader. The plots, 30′×18′ (6 rows), were then harrowed thoroughly to mix the insecticide in the top 3 to 4 inches of soil. Treatments were replicated four times in randomized blocks. Cabbage seed, Wisconsin Allseason was planted in the test area with a tractor-mounted precision planter on April 28. Seeds were placed 3 to 6 inches apart in the row and later thinned to give a plant every 18 inches in the row. Injury records were made on 20 mature roots dug from each plot in the fall. These roots were washed and scored only on a basis of injured and non-injured roots. Yield records were obtained from 40 feet of the center four rows in each plot and converted to tons per acre.

The results of this test are given in table 1. All treatments significantly reduced the number of roots showing injury. Dieldrin gave exceptionally good control at both concentrations tested, indicating that lower concentrations should be tested. Heptachlor applied at the rate of 6 pounds per acre also gave excellent control. The degree of injury to the cabbage roots from the aldrin, dieldrin and heptachlor plots was very slight. This injury seemed to indicate that the maggots survived only long enough to feed slightly on the roots, as the feeding scars were superficial and no puparia were observed around these roots. The control obtained with chlordane was rather disappointing. While the severity of root injury had not been categorized it was interesting to note that about 75 per cent of the injured roots from the chlordane plots was of a very heavy nature. Many puparia were found around the roots and in the feeding tunnels, indicating that a large number of the larvae had reached maturity. Chlordane was either not as toxic to the cabbage maggot as the other insecticides tested or else it had a poor residual toxicity. The

**Table 1.—Effectiveness of soil-applied insecticides for the control of the cabbage maggot in direct seedings of cabbage. Geneva, N. Y., 1950.**

| Treatment | Pounds Toxicant per Acre | Ave. No. Injured Roots per 20 | Yield Tons per Acre |
|---|---|---|---|
| Untreated | — | 18.3 | 31.0 |
| Aldrin | 4 | 6.3 | 32.6 |
| Aldrin | 8 | 4.0 | 31.5 |
| Chlordane | 4 | 15.0 | 33.7 |
| Chlordane | 8 | 8.3 | 29.8 |
| Dieldrin | 4 | 2.0 | 31.6 |
| Dieldrin | 8 | 2.0 | 33.3 |
| Heptachlor | 2 | 8.0 | 30.0 |
| Heptachlor | 6 | 1.8 | 28.4 |
| L.S.D. | (19:1) | 2.2 | |
| | (99:1) | 3.0 | |

[1] Journal Paper No. 951, New York State Agricultural Experiment Station, Geneva, N. Y., November 12, 1953.

latter seemed unlikely as tests with wireworms indicated otherwise (Rawlins *et al.* 1949).

There was very little difference in yield between the various treatments, and it was interesting to note that the average number of roots injured is not correlated with yield. Most of the root injury occurred during the second and third generations of the insect, but even where severe, as in the untreated plots, this was not reflected in a yield decrease. Despite the fact that the control records were not obtained on seedling cabbage plants, treatments capable of protecting roots through the second and third generations of the maggot should be effective during the first generation or in the cabbage seedling stage.

1951 EXPERIMENTS.—The plots in the 1950 experiment were replanted to cabbage, Wisconsin Allseason, without further insecticidal treatment and a similar culture maintained. Seed was again planted with a precision planter which placed a seed every 6 inches in the row. This planting was a failure and was reseeded with a hand planter which gave a plant every 0.5 inch, and was subsequently thinned to give a plant every 18 inches in the row. As in 1950, first generation maggot injury was negligible and injury records were made on 25 mature roots per plot in the fall. The roots were washed and graded into four categories, 0, 1, 2 and 3 indicating uninjured, slight, moderate and severe injury, respectively. The category number was multiplied by the number of roots in it, and the sum of the four resulting products constituted the injury index for the plot. The highest possible score, indicating all roots severely injured, is 75. Yields were taken from 40 feet of the four center rows.

The results of this test on the residual toxicity of the four insecticides are given in table 2. Dieldrin applied at the rate of 8 pounds per acre was the only treatment that appeared to have any appreciable degree of residual toxicity, but even this degree of cabbage maggot control was not of commercial importance. Thus, land treated the preceding year for some soil-inhabiting insect such as wireworms would require retreatment in order to obtain control of the cabbage maggot. There was no significant difference in yields between

**Table 2.—Residual toxicity of soil-applied insecticides to the cabbage maggot in direct seedings of cabbage. Geneva, N. Y., 1951.**

| TREATMENT | POUNDS TOXICANT PER ACRE | AVE. INJURY INDEX | PER CENT REDUCTION OVER UNTREATED[1] | AVE. YIELD TONS PER ACRE |
|---|---|---|---|---|
| Untreated | — | 56.0 | — | 19.0 |
| Aldrin | 4 | 49.8 | 11.2 | 17.2 |
| Aldrin | 8 | 46.0 | 17.9 | 16.6 |
| Chlordane | 4 | 60.5 | — | 19.9 |
| Chlordane | 8 | 61.8 | — | 17.3 |
| Dieldrin | 4 | 44.3 | 20.9 | 16.8 |
| Dieldrin | 8 | 21.5 | 43.8 | 18.5 |
| Heptachlor | 2 | 56.8 | — | 17.7 |
| Heptachlor | 6 | 48.3 | 13.8 | 17.6 |
| L.S.D. | (19:1) | 8.4 | | |
| | (99:1) | 11.3 | | |

[1] Computed by Abbott's formula.

treatments nor any correlation between yield and control of the cabbage maggot.

In 1950 some plots had been treated with the same four insecticides, but here aldrin was tested at 2, 4 and 8 pounds per acre, dieldrin and chlordane at 1, 2, 4 and 8, and heptachlor at 1, 2 and 4 pounds per acre. Treatments were replicated four times in randomized blocks. Diluted insecticides were broadcast on top of the soil and then worked into the soil as before. In 1950 this land was fallowed and planted to rutabagas without further insecticidal treatment in 1951. Injury records were obtained on 50 rutabagas from each plot by categorizing the injury as in the preceding experiment. The highest possible degree of injury in this case would be 150.

The results of this residual toxicity test are given in table 3. Aldrin and dieldrin applied at the rate of 8 pounds per acre were the only treatments that showed a large reduction in the amount of injury incurred, but this reduction was not of economic importance.

In 1951 the method of applying an insecticide for the control of the cabbage maggot in direct seedings of cabbage was tested. Dieldrin was selected as the test insecticide due to previous performance. Three methods of application were tested, broadcast dust, broadcast spray, and seed furrow treatments. The broadcast treatment was at the rate of 2 and 4 pounds of toxicant per acre and applied as in previous experiments. The spray

**Table 3.—Residual toxicity of soil-applied insecticides for the control of the cabbage maggot in a planting of rutabagas. Geneva, N. Y., 1951.**

| TREATMENT | POUNDS TOXICANT PER ACRE | AVE. INJURY INDEX | PER CENT REDUCTION OVER UNTREATED[1] |
|---|---|---|---|
| Untreated | — | 127 | — |
| Aldrin | 2 | 126.5 | — |
| Aldrin | 4 | 138.3 | — |
| Aldrin | 8 | 73.3 | 42 |
| Chlordane | 1 | 129.0 | — |
| Chlordane | 2 | 138.5 | — |
| Chlordane | 4 | 133.3 | — |
| Chlordane | 8 | 128.3 | — |
| Dieldrin | 1 | 134.5 | — |
| Dieldrin | 2 | 133.5 | — |
| Dieldrin | 4 | 109.5 | 13 |
| Dieldrin | 8 | 65.3 | 48 |
| Heptachlor | 1 | 120.0 | — |
| Heptachlor | 2 | 121.5 | — |
| Hpetachlor | 4 | 102.8 | 19 |
| L.S.D. | (19:1) | 16.1 | |
| | (99:1) | 21.5 | |

[1] Computed by Abbott's formula.

application was applied at the rate of 4 pounds of toxicant (emulsifiable concentrate) per acre to the soil surface by means of a low-gallonage sprayer in 20 gallons of water per acre. Following application the treated soil was harrowed to a depth of 3 to 4 inches. In the third method the seed furrow was opened and seeded with a hand planter (covering hoes removed) and 1 per cent dieldrin dusted into the open furrow at the rate of 40 pounds per acre, or 0.6 pound of toxicant per acre. The furrow was closed with a hoe following treatment.

A 5×5 Latin square design was used with plots 20′×20′ (6 rows wide plus a small buffer zone). All plots were seeded to Wisconsin Allseason cabbage on May 18 with a hand seeder and thinned as in previous experiments. The first generation cabbage maggot infestation was negligible, due in part to the lateness of the planting. Injury records were made on 25 roots sampled from each plot in the fall and categorized for injury as before. The maximum degree of injury would be 75.

The results of this test are given in table 4. The amount of injury in the untreated plots was only moderate. There did not appear to be any differences between the three methods of application tested, and since there was such a low

**Table 4.—Difference between three methods of applying dieldrin for the control of the cabbage maggot in direct seedings of cabbage. Geneva, N. Y., 1951.**

| APPLICATION METHOD | POUNDS TOXICANT PER ACRE | AVE. INJURY INDEX | PER CENT REDUCTION OVER UNTREATED |
|---|---|---|---|
| Untreated | — | 46.6 | |
| Broadcast | 2 | 7.8 | 83.3 |
| Broadcast | 4 | 5.2 | 88.8 |
| Spray | 4 | 3.6 | 92.3 |
| Furrow | 0.6 | 3.4 | 92.3 |

rate of application per acre in the case of the furrow treatment, it would appear that this method showed the greatest promise.

1952 EXPERIMENT.—The seed furrow method of application was investigated more fully in 1952 as it showed such promise in 1951. Spray was selected in preference to the previously tested dust due to the simpler application machinery involved. A pair of garden tractor seeders were equipped with spray nozzles which applied the spray into the furrow after the seed was dropped. Insecticide treatments were applied in 8 gallons of water per acre at a pressure of 60 p.s.i. Four insecticides were tested. The high rates of application selected correspond closely (slightly higher) to the maximum dosage previously tested as broadcast treatments. Actually only one-ninth the dosage should be required in cabbage planted in 3-foot rows to give a concentration in the soil comparable to a broadcast application. Aldrin, dieldrin and heptachlor were tested at the rate of 0.25 and 1 pound of toxicant per acre, and chlordane at 1 and 2. Emulsifiable concentrates were used in all cases. Plots were 30 feet long and 4 rows wide with 6-foot buffers between plots. Treatments were replicated three times in randomized blocks. Seeding was done on May 1. First generation cabbage maggot infestation was negligible, so 50 roots were sampled from each plot and indexed for injury in the fall, with 150 being the maximum amount of injury possible. Cabbage heads were harvested for yield data from the whole plot or from 120 feet of row.

The results of this test are given in table 5. All treatments gave significantly better results than the untreated plots, with

**Table 5.—A comparison of seed furrow treatments for the control of the cabbage maggot in direct seeded plantings of cabbage. Geneva, N. Y., 1952.**

| Treatment | Pounds Toxicant per Acre | Ave. Injury Index | Ave. Yield Tons per Acre |
|---|---|---|---|
| Untreated | — | 104 | 10.3 |
| Aldrin[1] | ½ | 72 | 13.7 |
| Aldrin | 1 | 50 | 13.6 |
| Chlordane | 1 | 66 | 11.4 |
| Chlordane | 2 | 49 | 10.4 |
| Dieldrin | ½ | 54 | 10.7 |
| Dieldrin | 1 | 38 | 11.5 |
| Heptachlor | ½ | 52 | 10.3 |
| Heptachlor | 1 | 50 | 11.3 |
| L.S.D. | (19:1) | 26 | |
| | (99:1) | 36 | |

[1] Missing plot computed as per formula proposed by Yates (1933).

better control being obtained at the higher dosage. Dieldrin applied at the rate of 1 pound per acre gave the best results. Chlordane, in view of previous results, gave surprisingly good control but at a much heavier concentration than the other insecticides. The reason for the high yields in the aldrin-treated plots is not known, but it does not appear to be correlated with superior control of the cabbage maggot. While none of the treatments appeared to give outstanding control, this method of application showed promise for use in direct field seeding of cabbage and perhaps even in seedbed plantings, but requires much more investigation.

1953 EXPERIMENTS.—The four previously investigated insecticides were tested for the control of the cabbage maggot in the seedbed. Radishes were used as they are highly susceptible to infestation and the injury readily recorded. The tests were conducted in four widely dispersed plantings each consisting of four randomized blocks. Measured amounts of the wettable powder formulation of the insecticides were sprayed on the soil surface and then thoroughly raked into the top 3 to 4 inches of soil. Plots (15′×20′) were then seeded on April 21, 24, 29 and 30 for tests 1 to 4, respectively. Injury records were obtained in early June on 200 radishes randomly sampled from the center of each plot.

The results of these tests are given in table 6. Each figure in the table represents the average of the four plots in each test, thus the average number of injured radishes per 200. Chlordane gave unsatisfactory control at all the levels tested. Aldrin, dieldrin and heptachlor gave good control at all levels tested and appear to be superior insecticides for broadcast treatments in cabbage seedbeds.

SUMMARY.—Four insecticides were tested as broadcast soil treatments for the control of the cabbage maggot in direct seedings of cabbage in 1950 and plantings of radish in 1953. Chlordane did not compare favorably with aldrin, dieldrin and heptachlor in effectiveness where broadcast applications were made. The effective dosages for broadcast applications appeared to be 6 pounds of aldrin per acre, 3 to 4 pounds of dieldrin, and about 3 pounds of heptachlor. There did not appear to be correlation between yield of cabbage and injury from second and third generation cabbage maggot.

The residual toxicity of the four insecticides to the cabbage maggot in plantings of cabbage and rutabagas was tested in 1951 on land treated in 1950. None of the insecticides, at the concentrations tested, gave satisfactory residual control, but dieldrin at the rate of 8 pounds per acre in cabbage, and aldrin and dieldrin at 8 pounds per acre in rutabagas significantly reduced the amount of cabbage maggot injury.

There did not appear to be any difference between applying dieldrin as a broadcast dust, broadcast spray, or as a dust in the seed furrow for cabbage maggot control. The low application rate of the seed

**Table 6.—A comparison of broadcast soil insecticide treatments for the control of the cabbage maggot in the seed bed. Geneva, N. Y., 1953.**

| Treatment | Pounds per Acre | Ave. No. Infested Radishes per 200 | | | | Total | |
|---|---|---|---|---|---|---|---|
| | | Experiment | | | | | Standard Error of Mean |
| | | 1 | 2 | 3 | 4 | Ave. | |
| Untreated | — | 61.5 | 42.5 | 88.2 | 61.2 | 63.3 | 6.3 |
| Dieldrin | 2 | 2.5 | 1.8 | 1.8 | 2.5 | 2.1 | 0.4 |
| Dieldrin | 4 | 3.0 | 2.2 | 3.0 | 0.8 | 2.3 | 0.5 |
| Dieldrin | 6 | 2.5 | 0.0 | 0.8 | 0.2 | 0.9 | 0.4 |
| Aldrin | 4 | 5.5 | 3.8 | 1.0 | 3.0 | 3.3 | 0.7 |
| Aldrin | 6 | 2.2 | 2.0 | 1.0 | 0.5 | 1.4 | 0.3 |
| Aldrin | 8 | 2.0 | 0.5 | 2.3 | 0.2 | 1.2 | 0.5 |
| Chlordane | 4 | 40.0 | 23.0 | 32.5 | 31.8 | 31.8 | 3.2 |
| Chlordane | 6 | 32.2 | 12.0 | 20.5 | 19.8 | 21.1 | 3.9 |
| Chlordane | 8 | 25.0 | 15.0 | 25.5 | 12.8 | 19.6 | 2.9 |
| Heptachlor | 2 | 6.8 | 1.2 | 0.8 | 2.8 | 2.9 | 0.8 |
| Heptachlor | 4 | 2.0 | 1.5 | 0.0 | 0.0 | 0.9 | 0.4 |

furrow treatment tends to make it a preferred method.

Tests with a seeder-sprayer in 1952 were not entirely satisfactory, but dieldrin applied at the rate of 1 pound per acre as a spray in the seed furrow at the time of seeding showed the most promise. This method of control requires more thorough investigation, but it appears that direct seedings of late cabbage in the field could be protected from injury by the cabbage maggot.

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# Further Studies of Insecticides for Apple Maggot Control[1]

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Two earlier papers dealing with insecticides for control of the apple maggot, *Rhagoletis pomonella* Walsh, have been presented by the writer (Dean 1946, 1951) and the present discussion may be considered as a continuation of the series. As in the preceding reports, both laboratory and field tests are included, and the methods used are those described previously.

MATERIALS.—The insecticides tested were commercially formulated preparations and were used as received from the manufacturer. Their compositions were stated to be as follows:

*Aramite*—15% wettable powder.
*Blackleaf 253*—wettable powder containing 25% DDT and 3% paratbion.
*Compound 1189*—50% wettable powder containing 2,3,3a,4,5,6,7,7a,8,8-decachloro-3a,3,4,7,7a-tetrahydro-4,7-methanoindene-1-one.
*CS-708 (Dilan)*—25% wettable powder.
*DDT*—50% wettable powder.
*Diazinon*—25% wettable powder containing 0,0-diethyl-0-[2-isopropyl-4-methyl-pyrimidyl (6)] thiophosphate.
*Dieldrin*—25% and 50% wettable powders.
*Heptachlor*—25% wettable powder.
*Lead Arsenate*—standard spray formulation.
*Malathion*—25% wettable powder.
*Methoxychlor*—50% wettable powder.
*Parathion*—15% wettable powder.
*Q-137 (Perthane)*—25% and 50% wettable powders, 47.3% emulsion and 5% dust formulation.
*Strobane*—50% wettable powder containing a chlorinated mixture of alpha-pinene isomers having a chlorine content of approximately 66%

LABORATORY TESTS.—Methods of testing insecticides in the laboratory for toxicity to apple maggot flies used previously were of three types, as follows: *discontinuous exposure tests*, in which the test material is applied to a food film spread on one surface of the test cage, *continuous exposure tests*, in which the entire inner surface of the test cage is sprayed, and *controlled exposure tests*, a modification of the continuous exposure method in which the time of exposure to the spray film is controlled. In the present investigation, the continuous exposure method was not used but some materials were tested in a manner designed to show their relative residual efficiencies. The method was similar to the controlled exposure test in that approximately 50 flies were exposed in sprayed petri dishes for 24 hours, then transferred to clean rearing cages and mortalities noted over a 10-day period. The tests were repeated at 24-hour intervals for 14 days and thereafter on the seventeenth, eighteenth, twentieth and twenty-fourth days after spraying, using the same sprayed petri dishes throughout.

*Residual Efficiency.*—Fifteen per cent parathion, at the rate of 1 pound in 100 gallons, 50 per cent DDT at 2 pounds per

[1] Journal Paper No. 954, New York State Agricultural Experiment Station, Geneva (Dec. 3, 1953). This work is part of a cooperative project with the Bureau of Entomology and Plant Quarantine, U.S.D.A.

100, lead arsenate at 3 pounds and 25 per cent dieldrin and 25 per cent heptachlor at 4 pounds per 100 gallons, were tested for relative residual effectiveness by the method outlined above. Since the greatest kill occurred within the first 24 hours after exposure, mortality records at this point were selected for comparison and plotted on a spray-deposit-age scale (Figure 1). Only lead arsenate failed to give complete mortality at some time during the tests. Although the 1-day-old DDT residue also failed to give complete kill in 24 hours, at the age of 2 days and 6 days, it did. Mortalities from the DDT residue remained above 90 per cent for the first 7 days and then declined at a moderate rate. Parathion caused complete mortality for the first 3 days and then lost its effectiveness rapidly. Heptachlor was completely effective for the first 4 days and also on the sixth day. Mortality was still high on the eighth day and thereafter decreased very rapidly. Dieldrin gave a complete kill for the first 11 days and, again, on the thirteenth and fourteenth days. On the eighteenth day, mortality was still high but declined precipitously thereafter. As might be expected with a slow acting insecticide, lead arsenate caused low mortality rates at the 24-hour level throughout the test period.

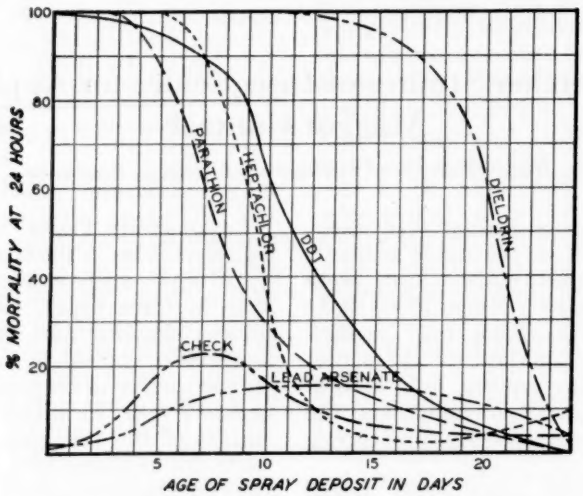


FIG. 1.—Effect of age of spray deposit on apple maggot fly mortality 24 hours after exposure.

*Discontinuous Exposure Tests.*—Dosage-mortality data were obtained for Compound 1189, *Strobane*, Diazinon and Aramite in these tests, the results of which appear in table 1. Compound 1189 caused complete mortality within five days at a dosage of ½ pound of 50 per cent wettable powder in 100 gallons, but at least 3 days were required to produce a complete kill when 4 pounds per 100 gallons of the same material were used. *Strobane*, at ½ pound of a 50 per cent wettable powder in 100 gallons required 9 days to cause complete mortality but, at 1 pound per 100 gallons, a total kill resulted in 2 days, while 2 or more pounds in 100 gallons caused complete mortality in the first 24 hours. Diazinon was the most toxic material in this group of tests, one or more pounds of a 25 per cent wettable powder per 100 gallons giving complete kill in the first 24 hours. In another series of tests, amounts less than ½-pound of 25 per cent Diazinon in 100 gallons failed to cause total mortality in the 10-day test period and, at the ½-pound level, 5 days were required to reach this degree of kill. An unusually high mortality occurred in the check for this series of tests. Aramite was included in the tests because of grower reports that it was stated to have value for apple maggot control. An unexpectedly high toxicity to the flies was shown but it was not sufficient to indicate that the material would be of practical value under field conditions.

*Controlled Exposure Tests.*—When exposed to spray residues of Compound 1189

**Table 1.—Results of laboratory tests on apple maggot adults, 1953.**

| Material | Exposure: Discontinuous — Amount in 100 Gals. | Per Cent Mortality Accumulated in—Days: 1 | 5 | 10 | Exposure: Controlled — Pounds per 100 Gals. | Exposure Minutes | Per Cent Mortality Accum. in—Days: 1 | 5 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| 50% Compound 1189 | ½ lb. | 6 | 100 (5)[1] | | 2 | 5 | 0 | 6 | 10 |
| | 1 lb. | 31 | 100 (4) | | | 10 | 14 | 86 | 92 |
| | 2 lbs. | 32 | 100 (3) | | | 15 | 11 | 100 | — |
| | 4 lbs. | 41 | 100 (3) | | | 30 | 6 | 96 | 98 |
| | | | | | | 60 | 0 | 87 | 90 |
| 50% Strobane | ½ lb. | 27 | 94 | 100 (9) | 2 | 5 | 10 | 71 | 78 |
| | 1 lb. | 94 | 100 (2) | | | 10 | 46 | 92 | 92 |
| | 2 lbs. | 100 | | | | 15 | 56 | 96 | 98 |
| | 4 lbs. | 100 | | | | 30 | 96 | 100 (2) | |
| | | | | | | 60 | 100 | | |
| 25% Diazinon | 1 lb. | 100 | | | 4 | 5 | 100 | | |
| | 2 lbs. | 100 | | | | 10 | 100 | | |
| | 4 lbs. | 100 | | | | 15 | 100 | | |
| | 8 lbs. | 100 | | | | 30 | 100 | | |
| | | | | | | 60 | 100 | | |
| 15% Aramite | 1½ lbs. | 8 | 70 | 74 | | | | | |
| Check | | 2 | 4 | 10 | | 0 | 8 | 46 | 54 |
| 25% Diazinon | 1 oz. | 6 | 35 | 47 | | | | | |
| | 2 oz. | 2 | 20 | 24 | | | | | |
| | 4 oz. | 12 | 36 | 64 | | | | | |
| | 8 oz. | 22 | 100 | | | | | | |
| | 1 lb. | 92 | 100 (2) | | | | | | |
| Check | | 20 | 32 | 56 | | | | | |

[1] Figures in parentheses indicate the actual day on which complete mortality was attained.

for periods of from 5 to 60 minutes, complete mortality resulted in 5 days after a 15-minute exposure, but longer exposure periods failed to induce complete mortality during a 10-day period (Table 1). These conflicting results indicate that exposure periods in excess of 1 hour are needed to insure complete kill by Compound 1189. Results of the tests with *Strobane* indicate that it acts more rapidly. All flies were killed within 2 days after a 30-minute exposure to Strobane residues, and within 24 hours after a 60-minute exposure. Fifteen minutes exposure caused 96 per cent mortality in 5 days and 98 per cent mortality in 10 days. Diazinon killed very rapidly, all flies in the test succumbing during the first day after only 5 minutes exposure. The mortality rate in the check for this series of tests was quite high, being considerably greater than that in the group of flies exposed to Compound 1189 for 5 minutes.

ORCHARD TESTS.—The methods used for field testing were the same as those employed previously. Isolated blocks of trees, which were known to be infested by apple maggot, were treated with insecticides, employing a standard high-pressure orchard sprayer or a standard orchard duster to make the applications. Sprays were applied from the ground with guns, the entire tree being covered in one operation. Dusts were applied from two opposite sides. Fungicides, usually either wettable sulfur or ferbam, were generally used in the first one or two applications but not thereafter. Sprays were timed according to fly emergence and vary slightly from season to season. The second cover spray, in late June, is generally the first application of importance to apple maggot control but, as in 1952, significant fly emergence did not occur until the time of the third cover spray, in early July. The intervals between applications varied from 7 to 8 days for the dust and 10 to 13 days for sprays. All fruit from 6 or more trees was examined to determine the degree of infestation.

The insecticides tested, dates of application and percentages of the fruit found to be infested are given in table 2, together with the infestation of the pre-

**Table 2.—Results of orchard tests for apple maggot control, 1951–1953.**

| Test No. | Materials in 100 Gallons of Spray | Date of Application | Fruit Examined | | Per Cent Infested | Residue P.P.M. |
|---|---|---|---|---|---|---|
| | | | Variety | Number | | |
| 1 | 25% Q-137 4 lbs. | June 26, | McIntosh | 2,629 | 5.44 | |
| | | July 9, | McIntosh | 2,430 | 0.29 | |
| | | July 20, | McIntosh | 3,935 | 0.36 | |
| | | July 30 and | McIntosh | 2,569 | 0.70 | |
| | | Aug. 9, 1951 | McIntosh | 3,097 | 0.36 | |
| | | | McIntosh | 731 | 0.27 | |
| | | Total | | 15,391 | | |
| | | Average | | | 1.24 | |
| | | 1950 Average (estimated) | | | 75± | |
| 2 | 50% methoxychlor 2 lbs. | June 26, | McIntosh | 123 | 7.09 | |
| | | July 9, | McIntosh | 192 | 11.21 | |
| | | July 20, | McIntosh | 346 | 18.85 | |
| | | July 30 and | McIntosh | 493 | 39.66 | |
| | | Aug. 9, 1951 | McIntosh | 331 | 30.51 | |
| | | | McIntosh | 338 | 26.28 | |
| | | | McIntosh | 413 | 37.01 | |
| | | Total | | 2,236 | | |
| | | Average | | | 24.37 | 6.6 |
| | | 1950 Average (estimated) | | | 95± | |
| 3 | 50% methoxychlor 2 lbs. | July 3, | McIntosh | 982 | 0.71 | |
| | | July 14, | McIntosh | 1,485 | 1.55 | |
| | | July 24, | McIntosh | 1,600 | 0.75 | 8.0 |
| | | Aug. 4, | McIntosh | 1,851 | 0.54 | |
| | | Aug. 14 and | Delicious | 1,699 | 1.00 | |
| | | | Delicious | 2,155 | 0.42 | 8.5 |
| | | Sept. 6,[1] 1952 | Delicious | 1,133 | 0.26 | |
| | | Total | | 10,905 | | |
| | | Average | | | 0.75 | |
| | | 1951 Average (estimated) | | | 20± | |
| 4 | 25% Q-137 4 lbs. | July 7, | Wealthy | 2,063 | 0.44 | |
| | | July 17, | Wealthy | 1,145 | 1.05 | |
| | | July 27 and | McIntosh | 2,703 | 0.92 | |
| | | Aug. 7, 1952 | McIntosh | 1,837 | 3.54 | |
| | | | McIntosh | 3,583 | 0.78 | |
| | | | McIntosh | 3,403 | 0.53 | |
| | | Total | | 14,735 | | |
| | | Average | | | 1.21 | |
| | | 1951 Average (estimated) | | | 95± | |
| 5 | 25% DDT+3% parathion 2½ lbs. | July 7, | McIntosh | 844 | 48.70 | |
| | | July 17, | McIntosh | 785 | 19.87 | 1.0[2] |
| | | July 28 and | McIntosh | 1,687 | 45.64 | |
| | | | McIntosh | 248 | 42.74 | 0.07[3] |
| | | Aug. 7,[4] 1952 | Cortland | 650 | 32.92 | |
| | | | Cortland | 796 | 43.22 | |
| | | | Cortland | 568 | 72.36 | |
| | | Total | | 5,578 | | |
| | | Average | | | 43.64 | |
| | | 1951 Average (estimated) | | | 25± | |
| 6 | 25% malathion 2 lbs. | June 23, | Milton | 1,409 | 75.51 | |
| | | July 3, | McIntosh | 1,365 | 86.52 | |
| | | July 14, | McIntosh | 638 | 77.28 | |
| | | July 24, | McIntosh | 2,504 | 88.18 | |
| | | Aug. 4 and | McIntosh | 1,670 | 91,50 | |
| | | Aug. 14, 1952 | G. Delicious | 953 | 97.06 | |
| | | Total | | 8,539 | | |
| | | Average | | | 86.01 | |
| | | 1951 Average (estimated) | | | 95± | |

| Test No. | Materials in 100 Gallons of Spray | Date of Application | Fruit Examined | | Per Cent Infested | Residue P.P.M. |
|---|---|---|---|---|---|---|
| | | | Variety | Number | | |
| 7 | 50% compound 1189 2 lbs. | June 23, | McIntosh | | | |
| | | July 3, | Macoun, | | | 9.7[5] |
| | | July 14, | Cortland and | | | 13.9 |
| | | July 24, | G. Delicious | | | |
| | | Aug. 4 and | | | | |
| | | Aug. 14, 1952 | | | | |
| | | Total | | 490 | | |
| | | Average | | | 65.71 | |
| | | 1951 Average | | | 100 | |
| 8 | 50% Q-137 2 lbs. | June 23, | McIntosh | 1,446 | 0.76 | |
| | | July 3, | McIntosh | 1,551 | 1.29 | |
| | | July 13, | McIntosh | 1,572 | 1.14 | |
| | | July 24, | Cortland | 1,009 | 1.39 | |
| | | Aug. 3 and | Cortland | 1,690 | 3.02 | |
| | | Aug. 13, 1953 | Cortland | 711 | 1.12 | |
| | | Total | | 7,979 | | |
| | | Average | | | 1.45 | |
| | | 1952 Average | | | 43.64 | |
| 9 | 47.3% Q-137 emul. 1 qt. | June 22, | McIntosh | 1,849 | 16.12 | |
| | | July 1, | McIntosh | 1,470 | 17.41 | |
| | | Jyly 13, | McIntosh | 2,809 | 18.97 | |
| | | July 24, | McIntosh | 1,849 | 8.49 | |
| | | Aug. 3 and | McIntosh | 3,462 | 11.73 | |
| | | Aug. 13, 1953 | G. Delicious | 856 | 86.92 | |
| | | Total | | 12,295 | | |
| | | Average | | | 26.61 | |
| | | 1952 Average | | | 86.01 | |
| 10 | 5% Q-137 dust | June 24, | Delicious | 378 | 8.99 | |
| | | July 1, | Delicious | 808 | 23.39 | |
| | | July 9, | Delicious | 451 | 8.87 | |
| | | July 17, | Delicious | 276 | 13.77 | |
| | | July 24, | Delicious | 515 | 10.68 | |
| | | July 31, | Delicious | 464 | 10.56 | |
| | | Aug. 10 and | Delicious | 344 | 17.44 | |
| | | Aug. 18, 1953 | Delicious | 139 | 8.63 | |
| | | | Delicious | 251 | 3.58 | |
| | | | Delicious | 157 | 8.92 | |
| | | | Delicious | 140 | 5.00 | |
| | | | Delicious | 163 | 9.82 | |
| | | | Delicious | 130 | 19.23 | |
| | | | Delicious | 223 | 9.42 | |
| | | Total | | 4,439 | | |
| | | Average | | | 11.31 | |
| | | 1952 Average (estimated) | | | 85± | |
| 11 | 50% dieldrin ½ lb. | June 22, | McIntosh and | | | |
| | | July 1, | Macoun | 391 | 51.66 | <0.6[6] |
| | | July 13, | Cortland | 564 | 76.42 | |
| | | July 24, | G. Delicious | 56 | 50.00 | |
| | | Aug. 3 and | | | | |
| | | Aug. 13, 1953 | | | | |
| | | Total | | 1,011 | | |
| | | Average | | | 59.36 | |
| | | 1952 Average | | | 65.71 | |

| Test No. | Materials in 100 Gallons of Spray | Date of Application | Fruit Examined | | Per Cent Infested | Residue P.P.M. |
|---|---|---|---|---|---|---|
| | | | Variety | Number | | |
| 12 | 25% CS-708 4 lbs. | June 22, | Duchess | 485 | 0.12 | |
| | | July 1, | Red Astrachan | 1,404 | 0 | |
| | | July 13, | Red Astrachan | 1,739 | 0 | |
| | | July 24, | Early McIntosh | 2,058 | 0.34 | |
| | | Aug. 3 and | Cortland | 1,171 | 1.54 | |
| | | Aug. 13, 1953 | Hubbardston | 1,671 | 5.62 | 7.5[7] |
| | | | Hubbardston | 636 | 3.30 | |
| | | Total | | 9,164 | | |
| | | Average | | | 1.56 | |
| | | 1952 Average (estimated) | | | 95± | |

[1] Applied by grower to Delicious variety only.
[2] Analyzed for DDT only.
[3] Analyzed for parathion only.
[4] *Blackleaf* 253½-lb. plus 15 per cent parathion 1.6 lbs.
[5] Determined by General Chemical Division, Allied Chemical & Dye Corporation; all other analyses made by A. W. Avens, Dept. of Food Science & Technology, N. Y. State Agr. Expt. Station.
[6] Determined by Agricultural Chemicals Division, Shell Chemical Corporation.
[7] Determined by Research Department, Commercial Solvents Corporation.

ceding year. The latter serves as a check on the experiment since conventional checks are not practical in apple maggot control investigations. Tests No. 1, 4 and 8 employed wettable powder formulations of Q-137 at the rate of 1 pound of actual toxicant in 100 gallons. Marked reductions in fruit infestation resulted. When applied in emulsion form at the same rate of actual toxicant (Test 9), there was a considerable reduction in apple maggot infestation but not enough to be of practical value. Further tests are needed to show whether the lowered efficiency was due to the formulation or to local conditions in the test block. Q-137, as a 5 per cent dust (Test 10), did not reduce maggot injury as much as the wettable powder spray, but was more effective than the emulsion spray.

Promising results with methoxychlor were reported previously (Dean 1951). When the test was repeated in 1951 (Test 2), the control obtained was not satisfactory. Under the conditions existing in this test block, an application later than August 9 was needed to prevent infestation by flies migrating from nearby unsprayed trees. Under more favorable conditions in 1952 (Test 3), satisfactory reduction of injury was obtained. In this test, the grower applied 50 per cent methoxychlor wettable powder 2 pounds in 100 gallons to the Delicious trees on September 6. This application probably did not affect the results in any way since it was not a thorough one and was made to only part of the trees in the block.

The commercial preparation containing 25 per cent DDT and 3 per cent parathion used in Test No. 5 did not reduce apple maggot damage under the conditions existing in the test orchard in 1952. It is probable that the amounts of the insecticides composing the mixture were insufficient to give enough residual protection between sprays since both are known to be toxic to apple maggot adults. Malathion, as employed in Test No. 6, also failed to give satisfactory control under rather severe conditions of maggot infestation. This is also believed to be due to lack of residual toxicity. Compound 1189, at 1 pound of actual toxicant in 100 gallons (Test 7), did not reduce fruit infestation sufficiently to be of value although toxicity to the flies was demonstrated in the laboratory tests. Likewise dieldrin, which has also been shown to be toxic to the adults in the laboratory, failed to give significant control under field conditions (Test 11). In a previous field test with this material, applied three times at higher concentrations, no control resulted. The lower dosages and more frequent applications used in Test No. 11 improved the results only slightly.

The final field test, with CS-708, shows good control of apple maggot injury. Results with another formulation of this toxicant were previously reported (Dean 1951) under the designation CS-645A +CS-674A. This material caused severe russetting. Such injury was not seen in the 1953 test with the new formulation. However, in another orchard test employ-

ing the same CS-708 formulation, slight russetting of McIntosh apples was noted.

SUMMARY.—Residual properties of parathion, DDT, heptachlor, dieldrin and lead arsenate were compared in the laboratory. On the basis of kill of apple maggot flies during the first 24 hours after exposure, parathion caused mortality of 90 per cent or more for 3 days, DDT for 7 days, heptachlor for 8 days and dieldrin for 18 days. Mortalities from lead arsenate did not exceed 20 per cent. In laboratory tests, the insecticides Compound 1189, *Strobane* and Diazinon were highly toxic to the flies. Compound 1189 exhibited the slowest toxic action and Diazinon the most rapid. Aramite, at a rate equivalent to 1.5 pounds of a 15 per cent wettable powder in 100 gallons killed a fairly high proportion of the flies but was much less toxic than the other materials tested in the laboratory.

In orchard tests, wettable powder formulations of Q-137, at 1 pound of actual toxicant in 100 gallons, reduced heavy infestations of apple maggot to low levels when applied from four to six times during the season. When applied at the same rate in emulsion form, and as a 5 per cent dust, Q-137 was less effective. Methoxychlor, 1 pound actual in 100 gallons, gave only fair control in one test but was very effective under less adverse conditions. A commercially prepared mixture containing 25 per cent DDT and 3 per cent parathion, used at 2½ pounds in 100 gallons, failed to control apple maggot. Twenty-five per cent malathion, at 2 pounds in 100 gallons, was not effective enough to be of practical value, nor were 50 per cent Compound 1189 at 2 pounds in 100 gallons or 50 per cent dieldrin at ½ pound in 100 gallons. CS-708 gave good control when used at 4 pounds of a 25 per cent wettable powder in 100 gallons.

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# The Role of Food Plants and Weather in the Ecology of *Melanoplus mexicanus mexicanus* (Sauss.)[1]

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The lesser migratory grasshopper, *Melanoplus mexicanus*, is one of the most widely distributed and most destructive grasshopper species in North America. Every few years serious outbreaks occur and heavy damage to crops and range lands results. Up to the present time no satisfactory method of predicting these outbreaks, or of destroying them in the incipient stages, has been developed. This is due, at least in part, to the fact that through the years the following two impressions, which are not entirely correct, have become generally accepted as facts:

1. *Melanoplus mexicanus*, and North American grasshoppers in general, will devour (*and thrive on*) almost any food plant that may be available.
2. Outbreaks of *Melanoplus mexicanus* (and other grasshopper species) occur during or immediately following droughts, and low populations occur when weather conditions are more humid. *M. mexicanus* has become, in the minds of many, the direct pawn of the current weather conditions.

The first of these impressions has been disproved to a large extent in recent years through laboratory experiment and field observation; the second will quickly lose credence in the mind of anyone who critically attempts to correlate population fluctuations directly with any available

[1] Contribution from Montana State College, Agricultural Experiment Station. Project No. MS 38, Paper No. 319 Journal Series.

weather records. The object of the present discussion is to emphasize the recently discovered evidence that *Melanoplus mexicanus*, when the habitat permits, generally chooses plants favorable to its growth and vitality; that, although it may devour other species of plants in the absence of its favorites, it does not necessarily thrive on them; and, further, to show how seasonal and year to year variations in the general food plant complex may be much more important determinants in the build-up or decrease of *M. mexicanus* populations than weather conditions *per se*.

Various workers have demonstrated that, when given a choice, *Melanoplus mexicanus* exhibits marked preferences for certain species and varieties of plants. In field plot tests, in Canada, Jacobson & Farstad (1941) and McBean & Platt (1951) record significant differences in the amount of damage sustained by different wheat and barley varieties in the presence of damaging *M. mexicanus* populations. Skoog (1941) reports on food plant observations made in Montana during the 1939 and 1940 seasons. He presents the following list of native food plants utilized by *M. mexicanus*, arranged in the order of preference.

PREFERRED PLANTS:

Russian thistle, only while small sprouts (*Salsola pestifer*)
Tansy mustard (*Sophia sophia*)
Fanweed (*Thalaspi arvense*)
Shepherd's purse (*Capsella bursa-pastoris*)
Pepper grass (*Lepidium sp.*)
Blue grass (*Poa secunda*)
Rabbitbrush, while young (*Chrysothamnus sp.*)
Western wheatgrass (*Agropyron smithii*)
Needlegrass (*Stipa comata*)

PLANTS EATEN IN ABSENCE OF PREFERRED PLANTS:

Russian thistle (*Salsola pestifer*)
Caragana, elm and rosebush leaves
Sagebrush (*Artemisia tridentata*)
Buckbrush (*Symphoricarpos*)
Cactus (*Opuntia engelmanii*)
Blue grama grass heads (*Bouteloua gracilis*)
Nigger-wool (*Carex*)

PLANTS RARELY EATEN TO ANY EXTENT:

Rabbit-ear mustard (*Conringia sp.*)
Blue grama grass foliage (*Bouteloua gracilis*)
Pigeon grass (*Setaria viridis*)
Squirreltail grass (*Sitanion hystrix*)
Pigweed (*Chenopodium sp.*)
Canada fleabane (*Erigeron canadensis*)
Tumbleweed (*Amaranthus graecizans*)

The writer in 1953 observed the food habits of *Melanoplus mexicanus* in Montana in an old cultivated field, abandoned to nature and heavy grazing of livestock some 30 years ago. The vegetation consisted principally of the following:

Bluestem wheatgrass (*Agropyron smithii*)
Fringed sagebrush (*Artemisia frigida*)
Cheatgrass (*Bromus tectorum*)
Sandberg bluegrass (*Poa secunda*)
Slimflower scurfpea (*Psoralea tenuiflora*)
Prairie thermopsis (*Thermopsis rhombifolia*)
Needleleaf sedge (*Carex eleocharis*)

A considerable variety of other forbs and grasses was present in lesser numbers. During the first part of the season an outstanding preference was shown by all nymphal instars for the green succulent cheatgrass. Later, however, with the drying and maturing of most of the vegetation, the adults and remaining nymphs were observed to feed principally upon unidentifiable dry plant debris on the ground. Eating habits, too, changed from a hearty, more or less greedy type of feeding to a more restless, browsing, nibbling sort of reaction, as if perhaps the food were no longer as satisfying as it had been earlier in the season. Whether or not the food available in 1953 in this habitat was favorable to the increase of *Melanoplus mexicanus* has not been determined.

Shotwell (1930), Hebard (1938), Pfadt (1949), and Barnes & Nerney (1953)[2] indicate that alfalfa ranks high in the food preference list of *Melanoplus mexicanus*. Smith *et al.* (1952), Brett (1947), and Barnes & Nerney (1953), however, present evidence to show that, under laboratory conditions in Canada, Oklahoma, and Arizona, alfalfa is a food that is not conducive to the optimum growth and reproduction of this species. Pfadt (1949) concludes that alfalfa is a poor food if all stages of the grasshopper are confined to it, but is a fairly adequate food for the second or later stages. Pfadt's (1949) data show that dandelion, wheat, tansy mustard (*Descurainia sophia*), and cheatgrass are probably favorable food plants, that alfalfa is somewhat questionable, and that Russian thistle (*Salsola kali*), Kentucky bluegrass (*Poa pratensis*), and bluestem wheatgrass are unfavorable food plants. In further tests he lists the following in order of preference: dandelion, wheat, alfalfa, Kentucky bluegrass, sunflower (*Helianthus petiolaris*), tumblemustard (*Sisymbrium altissimum*), fringed sage-

[2] Barnes, O. L., and N. J. Nerney. 1953. Biology and Ecology of Grasshoppers. U. S. Dept. of Agr., Bur. Ent. and Plant. Quar. Unpublished reports.

brush, thistle (*Cirsium plattense*), bluestem wheatgrass, needle and thread (*Stipa comata*), threadleaf sedge (*Carex filifolia*), blue grama (*Bouteloua gracilis*), and lamb's quarters (*Chenopodium album*). Note that alfalfa and Kentucky bluegrass, though high on the preference list, are low on the favorability scale. Otherwise his data show a positive correlation between preference and favorability.

Barnes & Nerney (1953) present data which show that winter mustard (*Sisymbrium irio*) and Johnson grass (*Sorghum halepense*), commonly found in Arizona alfalfa fields, are favorable foods for the vitality and increase of *Melanoplus mexicanus;* that nettleleaf goosefoot (*Chenopodium murale*) is moderately favorable; and that alfalfa and Bermuda grass (*Cynodon dactylon*) are unfavorable. With these five species of plants all available to the grasshoppers, the order of preference appeared to be winter mustard, alfalfa, Johnson grass, nettleleaf goosefoot, and Bermuda grass. Smith *et al.* (1952), in tests of nine food plants, list them as follows in order of favorability as foods for *M. mexicanus:* wheat, barley, dandelion, brome grass, flax, oats, sweet clover, Russian thistle, and alfalfa. No choice was offered the grasshoppers in these tests. Anderson & Wright (1952) observed the food habits of *M. mexicanus* during the seasons of 1949 and 1950 in a Montana plains grassland habitat. They report feeding on a great variety of forbs and grasses, but were unable to note any particular specific food plant preferences. During these two seasons it should be noted that populations of this grasshopper declined at least 85 per cent in the area under observation. It is postulated by the writer that although Anderson and Wright observed *M. mexicanus* feeding upon at least 75 species of plants, the favorable ones were not present in sufficient numbers or in a desirable state of growth or maturity; consequently, no food preferences were shown, and the population declined.

On the basis of the evidence presented above, the conclusion naturally follows that certain food plants are much more favorable to the vitality and increase of *Melanoplus mexicanus* than are others, and that, with the exception of alfalfa, this favorability seems reasonably well reflected by the food preferences so far observed for this species. Further critical study in other portions of the tremendous range of *M. mexicanus* will undoubtedly disclose other favorable food plant species. Likewise, it is anticipated that various degrees of nutritional favorability will be more firmly established for the various plants, ranging from optimum down to submarginal. Further, future research in the field will recognize the important possibility that various degrees of preference for different foods may not necessarily always indicate a corresponding favorability of those foods for the growth and reproduction of the grasshopper.

The plants that have so far been reported as favorable for *Melanoplus mexicanus* fall for the most part into two general groups: small grain crops; and quick-growing, succulent, aggressive weeds, most of them annuals, capable of abundant and widespread growth when environmental conditions permit. In the small grain habitats, ordinary good tillage practices tend to offer so much competition to the egg stage of grasshoppers that these habitats need not be considered generally as primary sources of *M. mexicanus* infestation, although they are subject to serious invasion from other sources and may maintain relatively high populations for some time after being invaded. It is now postulated that the second group of favorable plants, the annual weeds, occurring on unfarmed habitats, is the major source of outbreaks of this species of grasshopper. Until recent years the average entomologist had little knowledge of the ecology of this type of vegetation. Plant ecologists, however, have a considerable store of information on the intermittent occurrence of "outbreaks" of these weeds. Let us note a few examples:

1. Talbot *et al.* (1939) on the annual vegetation of California: "The annual-plant cover is unstable and variable to a surprising degree. Percentages of individual species move back and forth along the scale of relative abundance, from year to year. The amount of vegetation produced annually and the dates of greening and of drying likewise vary. Pronounced changes in aspect occur, both from season to season and during a given season."

2. Weaver & Albertson (1940) on drought damage to Midwestern range lands: "The bare soil during periods with

moisture is populated with annual weeds, chief of which is Russian thistle. In many places it is only with difficulty that one can distinguish denuded pastures from weedy, tilled land."

3. Ramaley (1939) on sand-hill vegetation in northeastern Colorado: "A flora which approaches the mesophytic stage must have, for permanence, a greater rainfall than the plains of Colorado enjoy. Even deficiencies for single seasons are likely to impose difficulties which result in a decrease of individuals of certain species; such reduction of abundance may be or may not be balanced by increases of other species. In any event, the composition and appearance of a given area cannot and does not remain identical from year to year."

4. Sarvis (1941) on the Northern Great Plains flora: "It is an unusual season when some one species does not appear more conspicuous than the others or is outstanding. . . . Following the drought of 1934 many mustards appeared over the prairie. The most notable of these was peppergrass (*Lepidium densiflorum* Schrad.) . . . It was abundant clear across the northern Plains. . . . In the fall (of 1937) Russian thistles (*Salsola pestifer* A. Nels.) appeared in bunches over the prairies and entirely covered the ground over extensive areas. Such a condition was never known before according to available information."

5. Craddock & Forsling (1938) on spring-fall sheep range in southern Idaho: "The annual fluctuations in weather resulted in important changes in the amount of forage produced. . . . The start of forage growth in the spring varied from as early as March 20 to as late as April 24, or a range of 36 days, largely as the result of fluctuations in the time at which temperatures rose to levels favorable to plant growth."

6. Whitman *et al.* (1943) on North Dakota range lands: "The annual forbs showed wide fluctuations in abundance, being scarce during the drought seasons and very abundant in the years immediately following. The greatest abundance occurred in the year with the most favorable moisture conditions. . . . "

7. Costello & Turner (1944) on short grass ranges of the central Great Plains: "On any short-grass range, regardless of whether its prevailing condition is excellent, good, fair, or poor, forage production varies considerably from year to year. . . . The differences are primarily due to fluctuations in annual weather conditions, especially in the amount and distribution of spring and early summer rainfall. Heavy rainfall, especially if not well distributed through the growing season, does not necessarily result in high forage production."

*Melanoplus mexicanus* is known to favor habitats (Criddle 1921, Fletcher 1902, Shotwell 1930, Hebard 1937, and others) in which large populations of annual weeds are likely to be found (old abandoned fields, range lands in poor condition, etc.). Likewise, populations of this grasshopper are known to fluctuate in a manner similar to that described for certain of its food plants. However, since entomologists have not generally recognized that the species may be depending upon a few species of rather erratically occurring weeds for its optimum development and survival, research has not been directed to any extent toward establishing a connection between the grasshopper and its available food. Instead, weather and its direct effects upon the grasshopper have been the major items of ecological research, a great deal of it disappointingly unfruitful.

If, as the evidence indicates, *Melanoplus mexicanus* does prove to be dependent for its optimum needs upon a limited number of food plants in any particular area, then we shall have a much sounder basis on which to predict increases or reductions in numbers of the species. Parker (1939) says, "Outbreaks are ordinarily preceded by several years of gradual increase in grasshopper numbers followed by a year that is unusually favorable." In other words, according to the present interpretation, any grasshopper population is the direct product of the food plants that have been present during the current and recent seasons, and the indirect product of the weather which caused those food plants to be there in their current condition. Thus, a thorough knowledge of the condition and abundance of the principal food plants throughout any season, and their effect on the current population, will serve as an index for the more accurate prediction of the potential population that may be expected the following season. Ecologists working on the problem will not ig-

nore the known direct effects of weather upon grasshoppers, but will combine them with the food plant effects and emerge with a much more complete understanding of the ecology of *M. mexicanus* than is available at the present time.

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# Reduction of Pea Virus Spread by Insecticide Applications[1]

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The virus diseases of pea are among the plant virus diseases for which little control has been possible. The pea aphid, *Macrosiphum pisi* (Kalt.), is the most important vector of pea viruses and, possibly, the only important vector of these viruses. It winters on alfalfa and clover and migrates to peas in the spring and summer. Viruses which cause diseases of peas also winter in alfalfa and clover and are carried from these to peas by the migrating aphids. The pea aphid populations developing in the peas are responsible for secondary spread within the fields.

Reports, such as that of Ripper *et al.* (1950), prompted a consideration of the possibilities of reducing pea virus disease incidence through control of the pea aphid. Tests in 1951 using demeton in seed, soil and foliage applications gave some control of pea virus spread and indicated more appropriate dosages for further experiments. The work reported herein is concerned with further investigations on the problem of using insecticides to curtail the spread of pea viruses by the pea aphid.

Methods.—In 1952, Dwarf Telephone peas were planted on May 31. Six treatments and a check were included and the plots arranged in a 7×7 Latin square. Each plot consisted of 3 rows 20 feet long with 18 inches between rows within the plot and 3 feet between plots.

The insecticides used were parathion and demeton. The parathion formulation was an emulsifiable concentrate containing 25 per cent 0,0-diethyl 0-p-nitrophenyl thiophosphate. The demeton formulation was an emulsifiable concentrate containing 42 per cent 0,0-diethyl-0-2 (ethylmercapto)-ethyl thiophosphate. The rates and application schedules are given in table 1. The foliage applications were made with a spray machine rigged on a garden tractor and were applied in 23 gallons of water per acre. The soil applications were made with the same equipment by spraying the insecticidal solution on the ground and then raking it in. In making the virus disease counts all the plants in each plot were counted and categorized.

Little information is available concerning the identification of the virus diseases of pea in New York. Pea enation mosaic was the only one which could be identified with certainty in these tests. Although the other viruses were generally manifested by definite symptom types, these are not listed separately. There are two reasons for this. First, characterization of a pea virus disease by a symptom type, e.g. "streak," is not necessarily definitive. Hagedorn & Walker (1949) name six viruses which cause streak symptoms in peas. These six viruses differ widely in host range and vectors. A second reason for the grouping together of virus diseases other than enation mosaic was that, to the extent that the insect transmission of pea viruses is understood, pea enation mosaic virus appears to be transmitted by aphids in a manner different from the transmission of other pea viruses. It belongs to the group of viruses designated as "persistent" by Watson & Roberts (1939) on the basis of insect vector relationships (Chaudhuri 1950). Pea enation mosaic was found in the experimental plots with greater frequency than any other virus disease.

In 1953, Bonneville peas were planted with a grain drill in rows 7 inches apart on three dates. The three plantings were adjacent. Each planting consisted of eight plots 40×60 feet. The plots were separated by swaths 3 feet wide. A paired plot system was used, the pairs consisting of an untreated check and a three-application parathion schedule. The parathion was applied with a tractor-mounted, low-volume, low-pressure sprayer and each application consisted of 1 pint of 25 per cent emulsifiable concentrate applied in 19 gallons of water per acre. The spraying schedules are given in table 2. At the time of each application, the tractor was also run through the untreated plots to equalize equipment damage for purposes of taking yields.

Samples for estimating virus disease incidence were obtained by using a 3-×3-foot frame. All the plants enclosed by the

[1] Journal Paper No. 956, New York State Agricultural Experiment Station, Geneva, N. Y., December 10, 1953.

**Table 1.—Insecticide treatments to reduce pea virus spread in peas.[1] Geneva, N. Y.**

| TREATMENT | AMOUNT[2] | APPLICATION DATES | PER CENT VIRUS[3] | | PER CENT VIRUS REDUCTION |
|---|---|---|---|---|---|
| | | | Enation | Total | |
| None | — | — | 36 | 53 | — |
| Demeton, seed | [4] | — | 25 | 40 | 25 |
| Demeton, soil | 0.5 | May 31 | 20 | 31 | 42 |
| Demeton, foliage | 0.5 | June 16, 25 July 8 | 16 | 20 | 62 |
| Demeton, foliage | 0.5 | June 25 | 21 | 30 | 43 |
| Parathion, foliage | 0.25 | June 16, 25 July 8 | 12 | 24 | 55 |
| Parathion, foliage | 0.25 | June 16, July 8 | 22 | 35 | 46 |
| L.S.D. | (19:1) | | 7 | 8 | 15 |
| | (99:1) | | 9 | 11 | 21 |

[1] Dwarf Telephone variety planted May 31, 1952.
[2] Active ingredient per acre in pounds.
[3] Each figure is the mean of seven plots.
[4] Two-thirds ounce per bushel of seed.

frame were pulled and the number of diseased and healthy plants recorded. These records were taken 1 to 3 days before harvest. Four such samples were taken from each plot. Standard pea harvesting equipment was used in obtaining yield data.

RESULTS.—In 1952, considerable reduction of virus disease incidence was obtained with demeton applied to the soil at the rate of 0.5 pound per acre. The use of three parathion foliage sprays compared favorably with three demeton foliage sprays (Table 1). It is doubtful that three parathion sprays would compare thus favorably to three demeton sprays for pea virus control under all conditions. However, because of the encouraging results with parathion and because the use of demeton on food crops was not imminent, the 1953 experiments were carried out with parathion.

The virus disease incidence in the experimental plots was not high in 1953. Three parathion sprays reduced the number of virus-infected plants in all three plantings (Table 3). The differences in total virus disease incidence between the sprayed and unsprayed plots were very distinct. In each planting, the total per cent virus disease in the unsprayed plot having the lowest incidence always exceeded the total per cent in the sprayed plot having the highest incidence. In all of the 12 pairs of plots, the total per cent virus-diseased plants in the unsprayed plot of the pair always exceeded that of the sprayed plot. The pattern of differences for the incidence of enation mosaic was about the same as for the total per cent except in the first planting. In the first planting, the incidence of enation mosaic was extremely low and there was no reduction due to spraying.

Where pea fields are severely infected with viruses, the effect on yield is quite obvious. However, in lighter infestations this effect is not so well defined. In table 3, the mean difference in virus disease incidence between sprayed and unsprayed plots can be compared with the mean difference in yield per plot in each planting. The pea aphid populations were very low and could not have caused direct injury by feeding. Thrips and plant bugs occasionally become abundant in peas, but these insects were not a factor here. Thus it seems safe to assume that the increased yields in the sprayed plots were due to reduced virus disease incidence.

Table 4 presents the amount of disease reduction in each of the three plantings compared to the increased yields converted to an acre basis. Calculations of the value increases are based on prices paid for peas in western New York in the 1953 season. Since the price of peas depends on quality, as judged by tenderometer measurements (Martin 1937), the increase in value between the three plant-

**Table 2.—Dates of parathion spray applications and cultural operations. 1953.**

| PLANTING NO. | DATE PLANTED | DATES OF SPRAYING | | | DATE HARVESTED |
|---|---|---|---|---|---|
| I | April 21 | May 29 | June 8 | June 19 | July 3 |
| II | May 11 | June 8 | June 19 | June 29 | July 13 |
| III | May 22 | June 8 | June 19 | June 29 | July 17 |

**Table 3.—Effect of parathion sprays on virus incidence and yield of Bonneville peas. Geneva, N. Y. 1953.**

| Planting Number and Date | Plot Pair No. | Per Cent Virus: Enation mosaic | | Per Cent Virus: Total | | Yield (Pounds per Plot) | |
|---|---|---|---|---|---|---|---|
| | | Sprayed | Check | Sprayed | Check | Sprayed | Check |
| I | 1 | 2.0 | 1.9 | 2.8 | 14.6 | 151 | 138 |
| April 21 | 2 | 0.6 | 0.6 | 3.6 | 10.0 | 146 | 146 |
| | 3 | 1.7 | 0.0 | 3.9 | 15.6 | 156 | 142 |
| | 4 | 0.0 | 2.1 | 2.5 | 13.9 | 146 | 151 |
| | Mean | 1.1 | 1.2 | 3.2 | 13.5 | 150 | 144 |
| | Mean Dif. | 0.1 | | 10.3 | | 6 | |
| II | 1 | 5.9 | 11.6 | 9.1 | 29.3 | 102 | 92 |
| May 11 | 2 | 2.2 | 8.9 | 5.0 | 20.2 | 124 | 97 |
| | 3 | 4.4 | 8.3 | 9.4 | 29.0 | 100 | 92 |
| | 4 | 2.7 | 20.6 | 10.2 | 37.3 | 102 | 74 |
| | Mean | 3.8 | 12.4 | 8.4 | 29.0 | 107 | 89 |
| | Mean Dif. | 8.6 | | 20.6 | | 18 | |
| III | 1 | 2.5 | 14.4 | 8.7 | 27.3 | 94 | 84 |
| May 22 | 2 | 2.7 | 7.0 | 7.8 | 16.8 | 118 | 100 |
| | 3 | 8.0 | 10.9 | 11.8 | 18.7 | 79 | 85 |
| | 4 | 3.0 | 9.4 | 13.1 | 24.8 | 82 | 65 |
| | Mean | 4.0 | 10.4 | 10.4 | 21.9 | 93 | 83 |
| | Mean Dif. | 6.4 | | 11.5 | | 10 | |

ings is not directly proportional to increase in yield. As the tenderometer reading rises, the unit value of peas decreases (see Sayre *et al.* 1953). The tenderometer reading of the peas in Planting I was 89; in Planting II, that of the sprayed plots was 110 and that of the unsprayed plots was 116; and in Planting III the tenderometer value was 80. Although three parathion sprays were applied to the peas, the cost of only two needs to be offset by increased yields due to virus disease reduction, since the third spray would have to have been applied for pea weevil control anyway. Table 4 gives the ratio of gain to the cost of two parathion applications. Thus, in Planting II, the increased value due to spraying was 2.7 times the cost of two parathion applications.

Tenderometer measurements were made from each plot in Planting II. The readings from the four sprayed plots were 102, 107.5, 107 and 125; those from the unsprayed plots were 115, 110.5, 120.5 and 120.5, respectively. In view of the limited amount of data, it is not possible to evaluate the significance of these differences between sprayed and unsprayed plots. However, this is an aspect of the possible effect of virus disease reduction which should receive further consideration. Virus-diseased plants are likely to produce fewer filled pods than healthy plants, and these peas would be mature before the peas on the healthy plants in the same field. Furthermore, the proportion of younger peas on diseased plants is likely to be much smaller than on healthy plants. It is thus possible that, in some instances, the diseased plants might deleteriously alter the quality, as judged by tenderometer readings, of the yield as a whole.

DISCUSSION.—When contemplating the reduction of pea virus spread by aphid control, certain general considerations would seem to apply. Infective aphids migrating from alfalfa and clover carry viruses to pea fields, thus establishing primary infections. Further spread within the field is due to the aphid populations developing therein. Secondary spread may also be due to non-infective aphids mi-

**Table 4.—Relation of virus reduction to increased yield in three plantings of peas. Geneva, N. Y., 1953.**

| Planting | Per Cent Virus: Sprayed | Per Cent Virus: Unsprayed | Yield (Pounds per Acre): Sprayed | Yield (Pounds per Acre): Unsprayed | Ratio of Gain to Added Cost of Spraying |
|---|---|---|---|---|---|
| I | 3.2 | 13.5 | 2700 | 2592 | 0.7:1 |
| II | 8.4 | 29.0 | 1926 | 1602 | 2.7:1 |
| III | 10.4 | 21.9 | 1674 | 1494 | 1.2:1 |

grating from alfalfa and clover, which acquire virus from infected plants already in the field and transmit it to healthy plants. The relative importance of each of these sources of virus spread is difficult to assess but, if a large proportion of the spread is due to the aphid population developing in the field, insecticide applications designed to keep down the aphid population should result in reduction of virus spread. Since an aphid can inoculate a plant with a virus in such a very short time, it is unlikely that virus infections due to infective migrating aphids arriving in the field can be prevented on an economic basis with present insecticides. It is also unlikely that virus spread can be appreciably controlled where migrating aphids acquire a non-persistent type virus in the pea field and transmit it to other plants. Viruses designated as "non-persistent" on the basis of the manner in which they are transmitted by insects (Watson & Roberts 1939) require no incubation period in the insect vector, are retained for a few hours or less and can be acquired and transmitted in very short feeding periods, less than a minute (Sylvester 1949). The problem of reducing pea virus spread by control of the pea aphid will probably vary in different areas depending on the pattern and intensity of the pea aphid migrations from forage legumes to pea and on the subsequent population development in pea.

The number of parathion applications should be such as to give the greatest margin between increased value of yield and cost of insecticide applications. In western New York, this would probably indicate two or three applications. Although many fields in this area become severely infested, there are also many which have a low virus disease incidence Since the extent of virus infestations cannot be known in advance, all fields may have to be treated and the gain accrued in heavy infestations used to partially offset the cost of treatment in light infestations. It may be that the largest group of light infestations can be eliminated by omitting the treating of the earliest planted fields. Although severe virus infestations may occur in early plantings, the frequency appears to be lower, in general, than in later plantings. Where the virus disease incidence reaches 100 per cent, there are very likely to be situations where parathion applications will not provide worthwhile control.

SUMMARY.—Pea virus disease incidence in small plots was reduced by using demeton and parathion foliage sprays to control the pea aphid from 53 per cent in untreated plots to 24 per cent in plots receiving three parathion sprays.

Parathion was used on large plots that were harvested by commercial processes. In three plantings three parathion sprays reduced the relatively low virus disease incidence from 13.5 to 3.2 per cent, from 29.0 to 8.4 per cent and from 21.9 to 10.4 per cent.

Yield records were taken in order to evaluate the economic significance of the disease reductions. It appears that in some cases a reduction of as little as 11.5 per cent is of economic significance in that the gain is more than sufficient to pay for the cost of parathion applications. Where the reduction reached 20 per cent, there was a very definite economic gain resu'ting from the value of the increased yield.

It is believed that further experiments are warranted in western New York, as well as other areas, with the objective of possibly introducing the practice of applying insecticides to reduce virus spread in peas.

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# Control of Onion Maggot on Seed Sets in the Connecticut Valley

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The onion maggot, *Hylemya antiqua* (Meig.) is considered a serious pest in the culture of onion seed sets in the Connecticut Valley. In the past it has been one of the causes of serious losses suffered by farmers growing this crop. The infestations of this insect cannot be predicted from year to year. It may cause tremendous damage one year and during the following season the infestation may be hardly noticeable. Generally, very little control practice has been carried on because the infestations are so unpredictable and older methods entailed considerable labor and expense. With the advent of newer residual insecticides, control of the onion maggot appears to be within the reach of every farmer.

The term "seed set" is applied to those onions grown from seed which are to be planted as sets the following year. The seed to produce seed sets is sown at the rate of 40 to 60 pounds per acre in rows 2 to 3 inches in width. This heavy seeding produces a very dense stand of onions which is particularly susceptible to maggot damage.

The onion maggot attacks seed sets just as it does other types of onions. Eggs are laid around the stems of the plant or in cracks of the soil in close proximity to the onions. When the eggs hatch the larvae crawl to a stem and then follow the stem underground to the roots. Here they may destroy some of the roots or enter the onion itself through the root crown. In the case of seed sets one larva may destroy several young seedlings successively. Adult flies lay their eggs in groups, thus making possible the destruction of large sections of a row. Thirty to 50 per cent loss has been not uncommon. Poor quality seed sets are produced by the thinning effect of the larvae. Such thinned onions tend to grow too rapidly and produce large sets which will form flower stalks when planted the following year. This type of onion is virtually worthless. During the summers of 1951 and 1952 heavy losses caused by the onion maggot occurred throughout the Connecticut Valley growing areas. In contrast, the summer of 1953 proved to be a rather light maggot season.

The onion maggot has been destructive to onions in the United States for many years. Howard (1918), was among the first workers to start investigations on the control. His attempts to control the insect consisted primarily of introducing poisonous baits, made up of sodium arsenite, molasses, and onion slices, into the onion fields. This practice was not effective. Later, Eyer (1922), also using sodium arsenite, molasses and chopped onions, found that 24 bait cans containing these ingredients per acre, gave good control. He also recommended to the gardeners, a spray consisting of crude carbolic acid and soap emulsified in water. Flint & Compton (1925) devised other methods for control. They reported that both a corrosive sublimate ($HgCl_2$ 1 oz./10 gal. $H_2O$) solution, and a bordeaux oil emulsion showed some potential possibilities for the control of this pest.

Glasgow (1929) observed the fact that mercurous chloride (calomel) was less toxic to plants than mercuric chloride, and gave excellent control. Pepper & Nissley (1937) and Wright (1939) recommended the use of calomel which apparently gave good control in all their tests. Dustan (1937) found that using 1 to $1\frac{1}{2}$ pounds of calomel per pound of seed, injury was reduced to 5.7 per cent, as compared to 22 per cent injury in the checks. Matthewman *et al.* (1941) in investigations on the timing of applications for the control of onion maggot, noted that the recommended seed treatment of 1 to $1\frac{1}{2}$ pounds of calomel per pound of seed would give better control if supplemented by either mercuric chloride solution or 4 per cent calomel dust later in the season.

Not until 1946 were the new organic insecticides applied for onion maggot control. McLeod (1946), ran extensive tests and found that calomel gave very good control and that both DDT and BHC appeared very promising for the control of this maggot. He criticized the use of calomel as being too costly. Munro (1947), in North Dakota obtained 90 per cent

control of the maggot by means of spraying onions with 1 ounce of 25 per cent DDT per gallon of water. Maan (1947), using DDT in the powder form as a seed treatment, at the rate of 40 grams per 100 grams of seed, obtained better results than with calomel. Lange *et al.* (1951), working on the control of the seed corn maggot in northern California, suggested that 1 ounce of 25 per cent formulation of lindane per 100 pounds of large lima bean seeds together with an adequate fungicide, can be used in commercial field treatments. They also obtained information indicating that dieldrin, aldrin, and chlordane offer possibilities for control as seed treatments.

Three types of treatment were applied for the control of onion maggot in these investigations. The first was spraying. In this method the residual insecticide is deposited against adults as they come into the field for oviposition and larvae as they emerge from any eggs that have been deposited. The second method is called the dry seed treatment. This merely indicates that the seed and insecticide are mixed together in the absence of a sticker. The end result is an equally dispersed mixture of seed and insecticide. The third method has been called pelleting of seed. This process involves the wetting of the seed with the methyl cellulose sticker in order that the insecticide adhere to the seed and form pellets.

PROCEDURE.—The areas used for experimentally testing these methods were made available by farmers in the town of Sunderland, Massachusetts during the summers of 1952 and 1953. The soils of the onion growing areas of the Connecticut Valley are typically a fine mineral loam. They are well drained and fairly retentive of moisture. These fields were arranged into plots during planting, and all tests were replicated at least three times.

The method for evaluating the amount of damage produced by the maggots in seed sets was an indirect one. Since seed sets are sown thickly, it was decided to simplify the counting by using the number of inches of onions destroyed per 50 feet of row. These evaluations were made about 1 week prior to harvest of the crop. The damage recorded was that produced by the larvae throughout the growing season.

SPRAYING.—The possibility of control using a spray treatment was based on the hypothesis that the residue left on the plants and soil would kill the adults as they arrived in the fields to oviposit, and the larvae as they emerged from the eggs. The habits of this insect are such that control in this manner appeared possible. As the adults arrive in the field to oviposit they are quite active among the plants and readily come into contact with residual insecticides. Adults lay their eggs on the stems of onions or in cracks of the soil in close proximity to plants. When the eggs hatch the larvae emerge and seek an onion stem and crawl down toward the roots. Once there, they may feed on roots or they may enter the onion bulb through the root crown.

At the time of planting the rows of seed sets were spaced to allow a power sprayer drawn and powered by a tractor to pass through the field. The sprayer used in these tests was a conventional "Field Force" 6-row potato sprayer. It was equipped with an 18-nozzle boom which was slightly modified to produce an even spray covering 12 rows. Each 12 rows was considered a plot. Four applications of the insecticides were made during the season. The timing was based on the seasonal development of the onion maggot. The first treatment was made when the first adults were found. This coincided with the development of the onions which were just passing the "knee stage." Thus the first application occurred on May 12 and others followed at approximately 10-day intervals to cover the emerging period of the adults. Emulsions were used exclusively in these tests. Dieldrin, DDT, chlordane, heptachlor, aldrin and parathion were applied in amounts shown in table 1.

**Table 1.—Results of four spray treatments to control onion maggot damage to seed sets.**

| TREATMENT | POUNDS OF ACTUAL TOXICANT/ ACRE | INCHES DESTROYED/ 50 FEET OF ROW | PER CENT REDUCTION |
|---|---|---|---|
| Dieldrin | 0.50 | 10.3 | 65 |
| DDT | 0.60 | 12.4 | 58 |
| Chlordane | 2.0 | 13.4 | 55 |
| Heptachlor | 0.75 | 15.5 | 47 |
| Aldrin | 0.75 | 18.8 | 36 |
| Parathion | 0.25 | 20.3 | 31 |
| Check | — | 29.4 | — |
| L.S.D. 5%—6.3; 1%—8.6 | | | |

PELLETING SEED.—This method of application refers to the procedure of mixing seed and insecticide in the presence of a sticker. To each pound of seed was added 100 cc. of the sticker, *Methocel*, to which was then added the insecticide and in most cases a powdered fungicide, Arasan. The mixture was then agitated in a covered can by shaking. When thoroughly mixed the individual seeds resemble little pellets about $\frac{1}{8}$ inch in diameter. When dry, they are ready for planting. Control of the onion maggot with this method is dependent upon the residual action of the insecticide on the larvae as they make their way through the soil to the roots and bulb. The insecticide is deposited in the soil at the point where seed was dropped in planting and in soil through which the seed was carried during germination.

The plots in these tests were arranged at the time of planting. Each plot consisted of six rows and each insecticidal application was replicated 3 or 4 times. The insecticides, DDT, heptachlor, and dieldrin were used in combination with Arasan which was added for smut control. In order to insure the proper amount of coated seed to pass through the planter the openings were adjusted accordingly. Results obtained by the use of pelleted seed are shown in table 2.

**Table 2.—Results of the use of pelleted seed for the control of onion maggot.**

| TREATMENT | POUNDS OF DUST/ POUND OF SEED | INCHES DESTROYED/ 50 FEET OF ROW | PER CENT REDUCTION |
|---|---|---|---|
| 1% heptachlor | 0.5 | 31.8 | 15.9 |
| 5% DDT | 0.5 | 15.9 | 58.0 |
| 10% DDT | 0.5 | 1.2 | 96.8 |
| 1% dieldrin | 0.5 | 1.2 | 96.8 |
| Check | — | 37.8 | — |

L.S.D. 5%—14.6; 1%—20.6.

DRY SEED TREATMENT.—This is also a one-treatment method for onion maggot control. It simply requires the mixing of dry seed and powdered insecticide at the time of planting. One pound or more of seed was placed into a 2-gallon can and then the proper amount of insecticide was added. The cover was replaced and the seed and insecticide shaken vigorously to produce an equally dispersed mixture. This mixture was then placed into the hopper of the seed drill and planted. An even distribution of insecticide is deposited in the furrow with the seed and remains there as a barrier against the larvae. In order to insure the proper amount of seed to be discharged by the planter, adjustments had to be made. Control of onion maggot by this method is based on the same principles as those discussed under the pelleting method.

As in the pelleting method, the tests were planned at the time of planting and were likewise carried out on commercial farms, using 4 to 6 rows per plot and 3 to 4 replications per treatment. Tests during the summer of 1952 produced information on the effectiveness of the more promising insecticides. In 1953 tests were conducted to confirm results obtained in 1952 and also to determine the proper amounts of insecticides to be used in these methods. The results of these tests are presented in table 3.

**Table 3.—Results of dry seed and insecticide mixtures on the damage produced to seed sets by the onion maggot.**

| TREATMENT | POUNDS OF DUST/ POUND OF SEED | INCHES DESTROYED | PER CENT REDUCTION |
|---|---|---|---|
| 1% aldrin | 0.25 | 23.2 | 32.1 |
| 1% heptachlor | 0.25 | 22.7 | 33.5 |
| Calomel | 0.25 | 21.9 | 35.6 |
| 5% chlordane | 0.125 | 19.8 | 42.0 |
| 1% heptachlor | 0.50 | 14.4 | 57.8 |
| 5% DDT | 0.25 | 8.0 | 73.6 |
| 5% DDT | 0.50 | 3.2 | 90.8 |
| 10% DDT | 0.25 | 1.7 | 95.1 |
| 1% dieldrin | 0.25 | 1.5 | 95.5 |
| 1% dieldrin | 9.50 | 0.8 | 97.5 |
| 10% DDT | 0.50 | 0.5 | 98.6 |
| Check | — | 33.6 | |

L.S.D. 5%—2.4; 1%—3.2

DISCUSSION AND RESULTS.—The methods of insecticide application here considered present feasible control for the onion maggot. Expensive equipment can be eliminated and control carried on with very little labor or expense to the farmer. Spraying seed sets with power sprayers is a comparatively expensive procedure and it apparently does not give the desired amount of control. With four applications it may be observed in table 1 that by using dieldrin at the rate of 0.5 pound of actual toxicant per acre, a 65 per cent reduction in damage was obtained. DDT and chlordane gave approximately the same control as dieldrin. Heptachlor, aldrin, and parathion gave rather poor re-

sults, parathion being least effective and resulting in 31 per cent reduction. Spraying seed sets, appears at this time a rather poor method of control, both as regards effectiveness and cost. The loss in yields caused by spacing to allow spraying equipment to enter the fields is a prohibiting factor in itself. Expensive labor and equipment to do this job also adds to the disadvantages. It appears that four or more applications are necessary to obtain a desirable amount of control.

The data in table 2 show that the pelleted seed method gave very good control. Ten per cent DDT used at the rate of 0.5 pound per pound of seed and 1 per cent dieldrin used at the rate of 0.5 pound per pound of seed were exceptional in control, both reducing the damage by 96 per cent. Heptachlor and 5 per cent DDT gave considerably less control. It is quite apparent that this method is adaptable to a farm of any size. Treatment of the seeds was made in advance of planting and since no other applications are necessary throughout the season, this becomes a very valuable method of control to the busy farmer. Perhaps the only disadvantage of this method lies in the preparation of the pelleted seed. Mixing wetted seed and insecticide is a laborious task unless some sort of mechanical agitator is available. After the seed is pelleted it must be spread out in thin layers for drying. If large amounts of seed are involved a large floor space is necessary.

In contrast to the pelleting of seed, the dry treatment is most promising with reference to the ease of preparation and its effectiveness. The only equipment necessary in this method is a covered can for mixing the seed and insecticide. The treatment itself is simple and trouble-free as described in the procedure. Table 3 shows that excellent results were obtained with this method. Ten per cent DDT used at the rate of 0.5 pound per pound of seed and one per cent dieldrin used at 0.5 pound per pound of seed, both were highly effective, showing 97 per cent reduction in damage for dieldrin and 98 per cent reduction for DDT. Ten per cent DDT and one per cent dieldrin at 0.25 pound, per pound of seed, also was effective, resulting in a 95 per cent reduction in damage. Five per cent DDT used at 0.5 pound per pound of seed gave 90 per cent reduction, but heptachlor, chlordane, calomel, and aldrin proved quite unsatisfactory for good control.

SUMMARY.—Ten per cent DDT and one per cent dieldrin applied to onion seed as dry materials, and agitated to produce an evenly dispersed mixture of seed and insecticide, gave the most effective control of onion maggot. As good control was obtained with the same materials if applied to produce pelleted seed but it is more inconvenient to use this method at the time of planting and preparation.

Spraying for maggot control was apparently not as effective and was less desirable because it entails wider spacing of rows for use of power equipment. It is also more expensive in terms of labor and insecticide with a minimum of four applications needed to obtain a significant amount of control.

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# Control of Insect Pests of Ornamentals

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Years of experience have alerted nurserymen, arborists and others interested in protecting trees and shrubs from injurious insect pests to the possibility of phytotoxicity of dormant oil sprays on evergreens. The development of chlorinated hydrocarbon and organic phosphate insecticides has provided new materials for use on ornamentals in preference to dormant sprays.

Although under some conditions the newer insecticides may be injurious to certain plants, it would seem that they are much less hazardous than dormant oils. Hence this paper has been prepared to present the results of the use of several of the newer insecticides in place of dormant spray materials on ornamentals.

Three species of scale insects, two species of leaf miners, and two species of aphids are included in the study. Field experiments dealt with the control of the oystershell scale, *Lepidosaphes ulmi* (L.), the pine needle scale, *Phenacaspis pinifoliae* (Fitch), the azalea bark scale, *Eriococcus azaleae* Comst., the birch leaf miner *Fenusa pusilla* (Klug), the boxwood leaf miner *Monarthropalpus buxi* (Laboulb.), and two species of aphids, the apple aphid, *Aphis pomi* Deg., and the four-spotted hawthorn aphid, *Amphorophora crataegi* (Monell), both on English hawthorn.

Materials and Methods.—The chlorinated hydrocarbon insecticides used in the experiments were in emulsifiable concentrate formulations as follows: chlordane 48 per cent; aldrin 21.85 per cent; dieldrin 15 per cent; lindane 25 per cent, and gamma isomer of BHC 13.75 per cent. In addition four organic phosphate insecticides were used in emulsion form—malathion 57 per cent; diethyl-methylcoumarinyl thiophosphate (*Potasan*) 30.6 per cent; TEPP 20 per cent and parathion 25 per cent. Technical lauryl thiocyanate (*Loro*) 40 per cent and 40 per cent nicotine sulphate were also used. The experimental aphicide 1-isopropyl 3 methyl-pyrazolyl-(5)-dimethylcarbamate[1] was used as a 25 per cent emulsion. A modified phthalic glycerol alkyd resin[2] was used as an additional spreading and sticking agent at the rate of 4 to 16 ounces per 100 gallons of water. Treatments were made by means of a portable mist blower and a 3-gallon hand pressure sprayer.

Oystershell Scale.—There is only one brood a year in the northeast. Overwintering takes place in the egg stage and hatching commences at the end of May. By June 3, 54 per cent of the eggs under 222 scales had hatched in 1953. On June 6, when an estimated 95 per cent of the eggs had hatched on yellow wood, *Cladrastis lutia*, and 40 to 50 per cent on lilac, *Syringa vulgaris*, seven 5- to 7-foot trees of the former species and one 5-foot shrub of the latter were sprayed with malathion and *Potasan* at the rate of 1 to 400 and 1 to 800. All treatments were replicated once and randomized. On June 12 one-half of the plants in the experiment were resprayed. Control data was secured from three 3-inch twig samples taken at random from each plant 3 weeks after the first series of treatments. Because of the enormous number of young scales on the treated plants counts were made in 10 binocular microscope fields of 5.9 sq. millimeter area taken at random from each set of twig samples. Results indicated that one treatment of either of the two insecticides at the stated dilutions killed all scales. Scales that hatched subsequent to the first series of treatments did not survive the residual action of the insecticides.

Pine Needle Scale.—This insect overwinters in the egg stage. Hatching begins about the middle of May. In 1953, 89 per cent of the egg masses showed an estimated 50 per cent or greater hatch on May. 19. On May 26 all but a few egg masses had hatched completely. The second brood of pine needle scale revealed initial hatch on July 20. By the close of the first week in August, all eggs had hatched and the young had dispersed.

On May 27, malathion and parathion were sprayed on 3- to 5-foot *Pinus montana* (variety uncertain, perhaps *mughus* Zenari), seriously infested with pine needle scale, at rates shown in table 1.

[1] G-23611 (Isolan) Geigy Co.
[2] Triton B-1956.

Because of the scarcity of plants the treatments were not replicated or randomized. Information relative to control was secured from 10 needles taken at random from three 6-inch twigs per treatment. Counts of dispersed young were made 10 days after treatment by means of a binocular microscope. Owing to the good control obtained from the first treatments, no additional spraying was done. It was seen, however, that some of the young scales that hatched after treatment survived. This was more obvious in the parathion-sprayed plants. As a result a fairly heavy second brood appeared on the parathion treated plants at the two lowest dilutions. Concurrently the malathion-sprayed plants were virtually free from infestation. The much lower count of dead scales on the parathion treated plants resulted from dislodgement of the shriveled scales from the twig samples taken from these plants. The dead scales on the malathion-treated pines adhered longer.

**Table 1.—Control of pine needle scale.**

| Emulsion Used[1] | Rate of Treatment | No. of Dispersed Young | | Per Cent Control |
|---|---|---|---|---|
| | | Dead | Alive | |
| Malathion 57% | 1–800 | 447 | 10 | 97.8 |
| | 1–400 | 235 | 0 | 100 |
| | 1–200 | 520 | 0 | 100 |
| Parathion 25% | 1–800 | 167 | | 100 |
| | 1–400 | 63 | 5 | 92.6 |
| | 1–200 | 22 | 0 | 100 |
| Untreated | | 45 | 250 | |

[1] Applied May 37, 1953.

AZALEA BARK SCALE.—There is only one brood each year in Connecticut. Eggs commence hatching on or about June 20. Young migrants settle down in the axils of leaves or stems and along the main branches as far as the surface of the ground. Maturity is reached in the spring of the following year, at which time cottony or woolly masses form with eggs deposited therein.

The experiments reported here were carried on in 1951 and 1953. *Azalea kaempferi*, 18″ to 24″ high, were selected for treatment. In 1951 the first treatments were made on June 25 as indicated in table 2. At this time egg hatching was not complete. Hence a second series of treatments were made on July 9. Azaleas were sprayed only once in 1953 on August 6. Control data was obtained 4 weeks after treatment by counting all living and dead scales on three 3-inch twigs taken at random from treated and untreated plants. It would appear that the chlorinated hydrocarbon insecticides gave poor control of the scale, whereas the organic phosphates, thiocyanate and nicotine sulphate materials were by comparison highly efficient in this respect.

**Table 2.—Control of Azalea bark scale.**

| Emulsion Used | Rate of Treatment[1] | Number of Scales | | Per Cent Control |
|---|---|---|---|---|
| | | Dead | Alive | |
| TEPP 20% | 1–800 | 372 | 0 | 100 |
| | 1–400 | 279 | 0 | 100 |
| Nicotine sulfate 40% | 1–800 | 26 | 0 | 100 |
| | 1–400 | 13 | 0 | 100 |
| *Loro* 40% | 1–800 | 176 | 0 | 100 |
| | 1–400 | 138 | 0 | 100 |
| Lindane 25% | 1–800 | 24 | 11 | 68.5 |
| | 1–400 | 61 | 44 | 58.0 |
| Chlordane 48% | 1–800 | 16 | 42 | 27.5 |
| | 1–400 | 16 | 121 | 11.6 |
| Aldrin 21.85% | 1.800 | 38 | 149 | 20.3 |
| | 1–400 | 91 | 24 | 79.1 |
| Dieldrin 15% | 1–800 | 29 | 129 | 18.3 |
| | 1–400 | 36 | 101 | 27.0 |
| *Potasan* 30.6% | 1–800 | 514 | 0 | 100 |
| | 1–400 | 107 | 0 | 100 |
| Malathion 57% | 1–800 | 454 | 0 | 100 |
| | 1–400 | 139 | 0 | 100 |
| Untreated | | 484 | | |

[1] Two applications of each formulation were made except those containing *Potasan* and malathion which were applied only once.

BIRCH AND BOXWOOD LEAF MINERS.—Control of birch leaf miner with DDT, lindane, and aldrin and boxwood leaf miner through the use of lindane, chlordane, aldrin, dieldrin, DDT and nicotine sulphate are reported by Schread (1952, 1953). Only the use of malathion against these insects is discussed here.

Birch leaf miner experiments were randomized and replicated twice on May 20, using the gray birch, *Betula populifolia*, for the purpose. Average tree height was 6 feet. One 5.5-foot boxwood plant with a circumference of 18 feet was divided vertically into four parts; three parts for treatments made July 15 and the remaining part was used as a check. Control data were obtained by opening and examining with a binocular microscope 30 leaves taken at random from three 10-inch sprays of boxwood foliage per treatment and 100 birch leaves taken at random from the treated and untreated trees.

Results of the use of malathion for the control of birch leaf miner and boxwood leaf miner appear in table 3. Malathion gave a high order of control of birch leaf miner at all dilutions used, whereas miners of the boxwood were adequately

controlled at the highest concentration only.

**Table 3.—Birch leaf miner and boxwood leaf miner control with malathion.**

| Dilution Used[1] | No. of Miners | | Per Cent Control |
|---|---|---|---|
| | Dead | Alive | |
| *(Birch Leaf Miner (Treated May 20)* | | | |
| 1–1600 | 381 | 0 | 100 |
| 1–800 | 493 | 0 | 100 |
| 1–400 | 543 | 0 | 100 |
| 1–200 | 496 | 0 | 100 |
| None | | 225 | |
| *Boxwood Leaf Miner (Treated July 15)* | | | |
| 1–1600 | 226 | 117 | 69.4 |
| 1–800 | 167 | 122 | 57.7 |
| 1–400 | 227 | 0 | 100 |
| None | 9 | 181 | |

[1] Formulated from 57 per cent emulsion.

Control of Aphids.—Paul's Scarlet variety of English hawthorn *Crataegus oxyacantha* was used in the experiment. The trees were 6 years old, and averaged 10 feet in height. Treatments were made on July 8; each one was replicated twice and randomized. Results of the experiment appear in table 4. Because of the obvious increase in aphid population on the trees treated with malathion and BHC, they were resprayed on August 21. At this time the trees treated with experimental compound G-23611 were not resprayed. Data on control were obtained by averaging the number of aphids on 10 leaves taken at random from each treated tree at weekly intervals. In the interest of brevity data are tabulated at 3-week intervals only. Each material gave good control of aphids at all dilutions. Compound G-23611 appeared to display the longest residual action, especially noticeable at the two highest dilutions. Malathion was close to G-23611 in long-range effectiveness. BHC seemed to be less efficient than the other materials in preventing aphid buildup. This was more obvious at the two lower dilutions.

**Table 4.—Aphid control on hawthorn.**

| Emulsion Used[1] | Rate of Treatment | Average No. Live Aphids per 10 Leaves —No. Weeks After Treatment | | |
|---|---|---|---|---|
| | | 3 | 6 | 9 |
| G-23611 25% | 1–1600 | .03 | 1.3 | 9.3 |
| | 1– 800 | .07 | .03 | 0 |
| | 1– 400 | .03 | 0 | 0 |
| Malathion 57% | 1–1600 | 0 | .03 | .1 |
| | 1– 800 | 0 | 0 | 0 |
| | 1– 400 | .13 | 3.5 | 0 |
| BHC 13.75% g.i. | 1–1600 | 5.7 | 12.9 | 0 |
| | 1– 800 | .03 | 6.9 | 17.33 |
| | 1– 400 | .03 | 0 | 0 |
| Untreated | | 33.07 | 14.9 | 60 |

[1] All treatments applied July 8; a second application of formulations containing malathion and BHC was made August 21.

Summary.—When treatments of malathion and *Potasan* were made after most of the oystershell scale eggs had hatched, complete control was effected with one treatment at all dilutions. For the most part the first brood of pine needle scale was controlled with one treatment of malathion and parathion applied when egg-hatching was practically over. The exception to this was at one of the lower dilutions of each insecticide, where some carryover of infestation into the second brood occurred.

The Azalea bark scale was controlled completely with one treatment of malathion and *Potasan* after all eggs had hatched. Where treatments of TEPP, nicotine sulphate, and *Loro* were applied before all eggs had hatched, a second application of these materials was necessary. Two treatments of lindane, chlordane, aldrin, or dieldrin gave poor control of young scales at all dilutions used. When treatments were made on May 20 the first brood of birch leaf miner was controlled completely with one application of malathion at all dilutions. Boxwood leaf miner control was poor at the two lowest concentrations of malathion, but complete at the highest concentration.

Aphid control on English hawthorn was of a high order of efficiency following the initial treatments of G-23611, malathion and BHC. It was necessary, however, to treat a second time with the latter two materials to prevent severe aphid populations before the end of the summer. Trees treated once in early July with G-23611 showed no serious rise in aphid infestation during the summer.

## Literature Cited

**Schread, J. C.** 1952. Birch Leaf Miner Control. Conn. Agr. Expt. Sta. Cir. 182.
**Schread, J. C.** 1953. Boxwood Pests and Their Control. Conn. Agr. Expt. Sta. Bul. 565.

# Synergists with Allethrin Against the Body Louse[1]

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During the last several years considerable research has been conducted with materials as synergists with pyrethrum and various other insecticides against the body louse, *Pediculus humanus humanus* L. Bushland *et al.* (1944a) showed IN-930 (N-isobutylhendecenamide) to be an effective pyrethrum synergist. Carson & Eddy (1949) reported on the results obtained with 446 compounds as synergists with pyrethrum against the body louse. Recently, Eddy *et al.* (1954) demonstrated that the toxicity of certain phosphorus compounds against the body louse could be markedly increased by the addition of other materials.

Numerous materials have been tested as synergists with allethrin by various workers against a wide variety of insect pests. The information on allethrin, including the research on synergists, has been summarized by Roark (1952). During the last 3 years the authors have tested a large number of materials in combination with allethrin against the body louse. The results obtained in laboratory tests with 203 of these compounds are reported in this paper.

Methods.—The test procedures described by Bushland *et al.* (1944b) and Eddy (1952) were used to evaluate candidate synergists as cloth impregnants (beaker tests) and as powders (patch tests). Sulfoxide was used as the standard in practically all the tests because it is highly effective with both allethrin and pyrethrum against body lice. The body lice used in the experiments were from a laboratory colony maintained on domestic rabbits, as described by Culpepper (1944, 1948).

*Beaker tests.*—In the beaker tests the materials were dissolved in acetone or some other suitable solvent at the desired concentration, and 0.7 ml. of the solution was applied by pipette to circular pieces of woolen cloth 1.5 inches in diameter. The treated pieces were suspended on pins, allowed to dry for about an hour, and then placed in a 50-ml. beaker with 20 young adult lice, 10 of each sex. The beakers were held in an incubator at 30° C. and approximately 70 per cent relative humidity. Mortality records were taken after 24 hours.

The synergists were tested at a ratio of 10 parts to 1 part of allethrin. Usually the initial tests were made with the synergists at 0.05 per cent in combination with 0.005 per cent of allethrin, but some of the synergists were tested at 0.1 per cent in combination with 0.01 per cent of allethrin. The treated cloths that were effective in the initial test were held at room temperature and retested at various intervals until they no longer caused satisfactory knock-down or kill of lice. Materials that caused complete knock-down or kill of lice in the initial test were further evaluated at 0.025, 0.01, and 0.005 per cent to obtain data on the minimum lethal concentration. Usually only one test was run at the lower concentration.

*Patch tests.*—The most effective materials in beaker tests were further evaluated in powders on balbriggan cloth patches 4.9 inches square. One-half gram of a powder containing 0.1 per cent of allethrin and 1.0 per cent of the synergist in pyrophyllite was spread evenly over the cloth with a spatula and lightly rubbed in with the fingers. The treated cloths were fastened on boards slightly larger than the cloths to facilitate handling. Wide-mouthed metal jar rings (without the center disk), held in position with rubber bands, were used to confine the lice on the treated cloths. The procedure for testing the powders was the same as for the beaker tests.

*Classification of Synergists.*—The synergists were classified according to their relative knock-down or kill in each type of test. In the beaker tests both the minimum lethal concentration and the residual effectiveness were evaluated, but the materials subjected to the patch tests were classified only as to residual effective-

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[3] S. A. Hall and associates of the Division of Insecticide Investigations specially synthesized a majority of the compounds tested. D. L. Van Natta and A. S. Marulli assisted in the test work and M. D. Couch, J. Stonecipher, and P. Mason reared the test insects.

**Table 1.—Classification of materials as synergists with allethrin in laboratory tests against the body louse.**

| CHEMICAL | BEAKER TESTS | | PATCH TESTS |
|---|---|---|---|
| | Minimum Lethal Concentration | Residue | |
| Acetamide, *alpha*-(piperonyloxy)-*N*,*N*-dipropyl- | 1 | — | — |
| Acetanilide, *p*-acetyl- | 1 | — | — |
| Acetic acid, phenyl-, *alpha*-allylpiperonyl ester | 2 | 2–3[1] | 2 |
| *alpha-tert*-butylpiperonyl ester | 4 | 2–3 | — |
| *alpha*-isopropylpiperonyl ester | 3 | 2–3 | 2–3 |
| Acetophenone, 2,4-dihydroxy-, diacetate | 1 | — | — |
| Benzene, 1,2-methylenedioxy-4-[2-(octylsulfonyl)propyl]-(Sulfone 12672) | 3 | 4 | 4 |
| Benzhydrol, 3,4-methylenedioxy-, acetate | 1 | — | — |
| Benzoic acid, 3,4,5-trimethoxy-, piperonyl ester | 1 | — | — |
| Benzylamine, *N*-ethyl-*N*-phenyl- | 1 | — | — |
| Bicyclo[2.2.1]-5-heptene-2,3-dicarboximide, *N*-2-ethylhexyl- (MGK-264) | 2 | 3 | 2 |
| Bicyclo[2.2.1]-5-heptene-2,3-dicarboxylic acid, *cis*-,bis(2-ethylhexyl) ester | 1 | — | — |
| 1,3-Butadione, 2-butyl-1-phenyl- | 1 | — | — |
| 2-Butanol, 4-(3,4-methylenedioxyphenyl)-, acetate | 3 | 2–3 | — |
| 3-Buten-1-ol, 1-(*p*-methoxyphenyl)- | 1 | — | — |
| 1-(3,4-methylenedioxyphenyl)- | 1 | — | — |
| Butyric acid, *p*-cyclohexylphenyl ester | 1 | — | — |
| Caproic acid, *alpha*-allylpiperonyl ester | 3 | 3–4[1] | 1–2 |
| 9-Carbazole, *N*-chrysanthemummonocarbonyl- | 1 | — | — |
| Chrysanthemumic acid | 1 | — | — |
| *alpha*-allylcuminyl ester | 1 | — | — |
| *alpha*-allylpiperonyl ester | 3 | 4 | 4 |
| *alpha*-allyl-*o*-veratryl ester | 1 | — | — |
| *alpha*-amylpiperonyl ester | 3 | 4 | 4 |
| *alpha*-benzylpiperonyl ester | 3 | 2–3 | 2–3 |
| *alpha-tert*-butyl-*o*-methoxybenzyl ester | 1 | — | — |
| 2-(*p-tert*-butyl) phenoxyethyl ester | 1 | — | — |
| *alpha*-butylpiperonyl ester | 4 | 4 | 4 |
| *alpha-tert*-butylpiperonyl ester | 4 | 4 | 4 |
| cetyl ester | 1 | — | — |
| *p*-chlorobenzhydryl ester | 1 | — | — |
| *p*-chlorobenzyl ester | 2 | 2–3 | — |
| 2-chloroisopropyl ester | 1 | — | — |
| 2-chloro-6-methylphenyl ester | 1 | — | — |
| cholesteryl ester | 1 | — | — |
| cinnamyl ester | 1 | — | — |
| 2-cyclohexylcyclohexyl ester | 1 | — | — |
| 4-cyclohexylcyclohexyl ester | 1 | — | — |
| *alpha*-cyclohexylpiperonyl ester | 3 | 2–3 | 2–3 |
| 4,4′-dichlorobenzhydryl ester | 1 | — | — |
| diester with 2-ethyl-1,3-hexanediol | 1 | — | — |
| diester with vanillyl alcohol | 1 | — | — |
| ester with 4-hydroxy-4-methyl-2-pentanone | 1 | — | — |
| ester with thiophenol | 2[2] | 2 | — |
| *alpha*-ethylpiperonyl ester | 3 | 4 | 4 |
| geranyl ester | 1 | — | — |
| *alpha*-isopropylpiperonyl ester | 4 | 4 | — |
| *o*-methoxybenzyl ester | 1 | — | — |
| *p*-methoxybenzyl ester | 1 | — | — |
| *alpha*-(2-methylallyl)piperonyl ester | 4 | 4 | 4 |
| 2-methylcyclohexyl ester | 1 | — | — |
| 3,4-methylenedioxybenzhydryl ester | 2 | 2–3 | — |
| 4-(3,4-methylenedioxyphenyl)-*sec*-butyl ester | 4 | 4 | 4 |
| *alpha*-methyl-*p*-methoxybenzyl ester | 1 | — | — |
| 2-methyl-2-nitropropyl ester | 1 | — | — |
| *alpha*-methylpiperonyl ester | 3 | 4 | 2 |
| octyl ester | 1 | — | — |
| *alpha*-phenethylpiperonyl ester | 3 | 2–3 | 2–3 |
| phenyl ester | 1 | — | — |
| 1-phenylethyl ester | 2 | 2 | — |
| *alpha*-(3-phenylpropyl)piperonyl ester | 3 | 2–3 | 2–3 |
| *alpha*-propylpiperonyl ester | 3 | 4 | 3–4 |

| CHEMICAL | BEAKER TESTS | | PATCH TESTS |
|---|---|---|---|
| | Minimum Lethal Concentration | Residue | |
| Chrysanthemummonocarboxamide, *N*-amyl- | 1 | — | — |
| *N*-butyl- | 1 | — | — |
| *N*-heptyl- | 1 | — | — |
| *N*,*N*-dioctyl- | 1 | — | — |
| *N*,*N*-diphenyl- | 1 | — | — |
| Cinnamic acid, *alpha*-allylpiperonyl ester | 1 | 2–3[1] | — |
| *alpha*-cyano-3,4-methylenedioxy-, ethyl ester | 2 | 2–3 | — |
| ester with 4-hydroxy-4-methyl-2-pentanone | 1 | — | — |
| *o*-isopropoxy-, allethrolonyl ester | 1 | — | — |
| *o*-methoxy-, *cis*-, allyl ester | — | 2[1] | — |
| *o*-methoxy-, *cis*-, *alpha*-allylpiperonyl ester | 1 | — | — |
| 3,4-methylenedioxy-, allethrolonyl ester | 1 | — | — |
| 3,4-methylenedioxy-, ethyl ester | 2 | 2 | — |
| Cyclohexanecarboxylic acid, 1-hydroxy-, phenethyl ester | 1 | — | — |
| propyl ester | 1 | — | — |
| 1-propylbutyl ester | 1 | — | — |
| 1,2-Cyclohexanedicarboxylic acid, dibutyl ester | 2 | 2 | — |
| diethyl ester | 1 | — | — |
| dipropyl ester | 1 | — | — |
| Cyclohexanone, 2-methyl-2-phenyl- | 1 | — | — |
| Cyclohexenone, trimethyl(piperonyl)- (Synergist "Sy-2") | 1 | — | — |
| *m*-Dioxane, 5-butyl-5-ethyl-2-(3, 4-methylenedioxy-phenyl)- | 4 | 4 | 1–2 |
| 4,6-dimethyl-2-(3,4-methylenedioxyphenyl)- | 3 | 3 | 1 |
| 5-ethyl-2-(3,4-methylenedioxyphenyl)-4-propyl- | 3 | 3–4[1] | 2 |
| 4-methyl-2-(3,4-methylenedioxyphenyl)- | 2 | 2–3 | — |
| 5-methyl-4-(3,4-methylenedioxyphenyl)- | 2–4 | 3 | — |
| 2-(3, 4-methylenedioxyphenyl)- | 1 | — | — |
| 4,4,6-trimethyl-2-(3,4-methylenedioxyphenyl)- | 3 | 2–3 | 1 |
| 1,3-Dioxolane, 4,5-dimethyl-2-(3,4-methylenedioxyphenyl)- | 3 | 2–3 | — |
| 4-methyl-2-(3,4-methylenedioxyphenyl)- | 2 | 2–3[1] | — |
| 2-(3,4-methylenedioxyphenyl)- | 1 | — | — |
| Ethane, 1,1-bis(chlorophenyl)- | 1 | — | — |
| Ether, benzyl eugenyl (benzyl eugenol ether) | 2–4 | 2 | — |
| *alpha*-ethylpiperonyl methyl | 1 | — | — |
| Fencholic acid, *alpha*-allylpiperonyl ester | 4 | 4 | — |
| piperonyl ester | 4 | 4 | 2–3 |
| 2-Furanacrylic acid, *alpha*-allylpiperonyl ester | 1 | — | — |
| Furfuryl alcohol, *alpha*-allyl- | 1 | — | — |
| *alpha*-allyl-, acetate | 1 | — | — |
| 2-Furoic acid, *alpha*-allylpiperonyl ester | 2 | 1–2 | 1 |
| Glutaric acid, *alpha*-carboxy-*beta*-methyl-, triallyl ester | 3 | 3 | — |
| *alpha*-cyano-*beta*-methyl-, diethyl ester | 1 | — | — |
| Guaiacol, propionate | 1 | — | — |
| 1,5,9-Hendecatrien-4-ol, 6,10-dimethyl- | 1 | — | — |
| 10-Hendecenamide, *N*-isobutyl- | 2 | 4 | 1 |
| Heptylamine, *N*-butoxyethyl- | 1 | — | — |
| 2,4-Hexanediol, 3-ethyl- | 1 | — | — |
| Hydrocinnamic acid, *alpha*, *beta*-epoxy-*p*-methoxy-*beta*-methyl-, allyl ester | 1 | — | — |
| Isosafrole | 1 | — | — |
| Malathion | 1 | — | — |
| Malonic acid, piperonyl-, diethyl ester | 3 | 2–3 | — |
| piperonylidene, dibutyl ester | 3 | 4 | 4 |
| piperonylidene, diethyl ester | 1 | — | — |
| Mandelic acid, octyl ester | 1 | — | — |
| 3,4-methylenedioxy-, allyl ester | 1 | — | — |
| 3,4-methylenedioxy-, ethyl ester | 1 | — | — |
| 3,4-methylenedioxy-, isopropyl ester | 2 | 2–3[1] | — |
| 3,4-methylenedioxy-, methyl ester | 1 | — | — |
| 3,4-methylenedioxy-, propyl ester | 2 | 2–3[1] | — |
| 4,7-Methanoindene, 6-allyloxy-3a,4,5,6,7,7a-hexahydro- | 1 | — | — |
| *levo*-Menthol, propionate | 1 | — | — |
| Naphtho[2,3]-1,3-dioxole-5,6-dicarboxylic acid, 5,6,7,8-tetrahydro-7-methyl-, dipropyl ester (*n*-propyl isome) | 2 | 3 | — |
| Palmitic acid, *alpha*-allylpiperonyl ester | 1 | — | — |

| CHEMICAL | BEAKER TESTS: Minimum Lethal Concentration | BEAKER TESTS: Residue | PATCH TESTS |
|---|---|---|---|
| 1,4-Pentadien-3-one, 1,5-bis(3,4-methylenedioxyphenyl)- | 1 | — | — |
| Phenol, 2,4-dinitro-6-phenyl-, acetate | 1 | — | — |
| Phthalic acid, diisopropyl ester | 2 | 2 | — |
| dimethyl ester | 1 | — | — |
| Pimelonitrile, *gamma*-acetyl-*gamma*-methyl- | 1 | — | — |
| Pinene, ether with ethylene glycol | 1 | — | — |
| Piperidine, 1-(*o*-ethoxybenzoyl)- | 1 | — | — |
| 1-(*p*-ethoxybenzoyl)- | 1 | — | — |
| Piperonal | 1 | — | — |
| Piperonyl alcohol | 1 | — | — |
| *alpha*-allyl-, benzoate | 3 | 3 | — |
| *alpha*-benzyl- | 2 | 2–3 | — |
| *alpha*-benzyl-, acetate | 3 | 2–3 | 1 |
| *alpha*-*tert*-butyl-, acetate | 4 | 2–3 | — |
| *alpha*-*tert*-butyl-, formate | 3 | 2–3 | — |
| *alpha*-cyclohexyl-,acetate | 4 | 3 | 2 |
| *alpha*-cyclohexyl-, benzoate | 2[2] | 2–3[2] | — |
| *alpha*-ethyl-, acetate | 3 | 2–3 | — |
| *alpha*-isopropyl- | 3 | 4 | — |
| *alpha*-isopropyl-, acetate | 3 | 3 | — |
| *alpha*-isopropyl-, formate | 2 | 2–3 | — |
| *alpha*-methyl-, acetate | 1 | — | — |
| *alpha*-phenethyl- | 2 | 2–3 | — |
| *alpha*-(3-phenylpropyl)-, acetate | 3 | 4 | 2–3 |
| *alpha*-(3-phenylpropyl)-, formate | 3 | 3–4 | — |
| *alpha*-propyl- | 1 | — | — |
| *alpha*-propyl-, acetate | 3 | 2–3 | — |
| Piperonylamide, *N*-propyl- | 1 | — | — |
| *N*-*o*-tolyl- | 1 | — | — |
| Piperonyl butoxide | 2 | 3 | 3 |
| cyclonene | 2 | 3 | 3 |
| Piperonylic acid | 1 | — | — |
| butyl ester | 2 | 2 | — |
| ethyl ester | 1 | — | — |
| propyl ester | 1 | — | — |
| Pivalic acid, *alpha*-allylpiperonyl ester | 3 | 4[1] | 2 |
| 2-Propanol, 1-methoxy- | 1 | — | — |
| Propionic acid, *alpha*-allylpiperonyl ester | 3 | 2–3 | — |
| 6-amyl-*m*-totyl ester | 1 | — | — |
| 2-*tert*-butyl-6-isopropylphenyl ester | — | 3[1] | — |
| 2-*tert*-butyl-*p*-tolyl ester | 1 | — | — |
| 4-*tert*-butyl-*o*-tolyl ester | — | 2[1] | — |
| *alpha*-butylpiperonyl ester | 3 | 3–2 | — |
| *alpha*-*tert*-butylpiperonyl ester | 3 | 3 | — |
| *o*-cyclohexylphenyl ester | — | 3[1] | — |
| *p*-cyclohexylphenyl ester | — | 4[1] | 1 |
| *alpha*-cyclohexylpiperonyl ester | 2[2] | 3[2] | — |
| 2,4-di-*tert*-butyl-6-isopropylphenyl ester | — | 3[1] | — |
| 4,6-di-*tert*-butyl-*m*-totyl ester | 1 | — | — |
| ester with 2,5-di-*tert*-butylhydroquinone | 1 | — | — |
| 2,4-dichloro-1-naphthyl ester | — | 2–3[1] | — |
| 2,4-dichlorophenyl ester | 1 | — | — |
| diester with 2,4′-dihydroxybenzophenone | 1 | — | — |
| diester with 4,4′-dihydroxybenzophenone | — | 2–3[2] | — |
| *p*-(*alpha*,*alpha*-dimethylbenzyl)phenyl ester | 1 | — | — |
| diester with 1,5-naphthalenediol | — | 3[1] | — |
| *m*-ethylphenyl ester | 1 | — | — |
| *p*-ethylphenyl ester | 1 | — | — |
| eugenyl ester | 1 | — | — |
| *p*-isopropylphenyl ester | 1 | — | — |
| *alpha*-pentylpiperonyl ester | 3 | 2–3 | — |
| *alpha*-propylpiperonyl ester | 3 | 2–3 | — |
| Pyrrolidine, chrysanthemummonocarbonyl- | 1 | — | — |

| CHEMICAL | BEAKER TESTS | | PATCH TESTS |
|---|---|---|---|
| | Minimum Lethal Concentration | Residue | |
| Quinoline, 1-acetyl-1,2,3,4-tetrahydro-(*N*-acetyl-1,2,3,4-tetrahydroquinoline) | 1 | — | — |
| Senecioic acid, *alpha*-allylpiperonyl ester | 3 | 3 | — |
| *alpha-tert*-butylpiperonyl ester | 3 | 2–3 | 2–3 |
| 2-cyclohexylpiperonyl ester | 3[2] | 2–3[2] | 1–2 |
| *alpha*-(3-phenylpropyl)piperonyl ester | 3 | 2–3 | 4 |
| Sesamin concentrate | 1 | — | — |
| Styrene, (3,4-methylenedioxy)- | 1 | — | — |
| Sulfoxide (benzene, 1,2-methylenedioxy-4-[2-(octylsulfinyl)propyl]-) | 3 | 4 | 4 |
| Thiophosphoric acid, *O*-(*alpha*-allylpiperonyl)*O*,*O*-diethyl ester | 1 | — | — |
| 3-chloro-4-methylumbelliferone *O*,*O*-dimethyl ester (Bayer 21/200) | 1 | — | — |
| Toluene, *alpha*-allyl-*alpha*-allyloxy-3,4-methylenedioxy- | 2 | 2–3[1] | — |
| *alpha*-allyl-3,4-methylenedioxy-*alpha*-propoxy- | 2 | 2–3[1] | — |
| Umbelliferone, 4-methyl-, *O*,*O*-diethyl thiophosphate (Potasan) | 1 | — | — |
| Urea, 1-(*p*-sulfamylphenyl)- | 1 | — | — |
| Valeric acid, *delta* (3,4-methylenedioxyphenyl)-*beta*-oxo-, ethyl ester | 3 | 2–3 | — |

[1] Tested at 0.1 per cent, or twice the standard concentration.
[2] Synergism not clearly indicated owing to toxicity of material alone.

ness. These classifications were as follows:

BEAKER TESTS
Minimum lethal concentration
1. Incomplete at 0.05 per cent
2. Complete at 0.05 per cent, but not at 0.025 per cent
3. Complete at 0.025 per cent, but not at 0.01 per cent
4. Complete at 0.01 per cent, but not at 0.005 per cent

Residual effectiveness at 0.05 per cent
1. Incomplete in initial tests
2. Complete in initial tests only
3. Complete for 1 to 6 days
4. Complete for 7 or more days

PATCH TESTS, residual effectiveness at 1 per cent
1. Complete for 0 to 3 days
2. Complete for 4 to 7 days
3. Complete for 8 to 12 days
4. Complete for 13 or more days

Allethrin and most of the synergists showed little or no toxicity when tested alone at the concentrations used in the initial tests. However, several of the test materials exhibited considerable toxicity alone; consequently, their role as synergists was not clearly indicated. Only when a material caused high or complete knock-down or kill of lice at a concentration at which neither it nor allethrin was toxic alone was synergism considered to be indicated.

RESULTS.—The results of these tests are presented in table 1.

BEAKER TESTS.—Slightly more than one-half of the 203 synergists tested failed to increase the minimum lethal concentration of allethrin (class 1). About one-third of the materials were definitely synergistic (classes 2 and 3), and 11 compounds, or a little more than 5 per cent, markedly increased the toxicity of allethrin (class 4).

On the basis of minimum lethal concentration the 11 class 4 synergists caused complete knock-down or kill of lice at 0.01 per cent in combination with 0.001 per cent of allethrin, and some of them caused high mortality of lice at one-half this concentration. Allethrin alone caused little or no mortality at 0.005 per cent, 40 to 95 per cent at 0.01 per cent, and 100 per cent knock-down or kill of lice at 0.025 per cent. Comparisons of the results with allethrin alone and in mixtures indicate that the better synergists increased the toxicity of allethrin 10 to 20 times or more.

Some of the synergists in class 4 on the basis of minimum lethal concentration were not in this class on a residue basis. The standard, sulfoxide, was rated class 3 in the tests of minimum lethal concentration but class 4 in the residue tests.

PATCH TESTS.—A total of 37 compounds were tested in powder form on cloth patches. Most of the class 4 and the more effective class 3 cloth impregnants in the previous tests were included.

Six materials were effective for only 0 to 3 days (class 1). Six materials were effective for 4 days but not more than 7 days (class 2). Eight synergists that proved effective for 4 but not more than 12 days were not tested at the proper in-

terval to definitely place them in either class 2 or in class 3. These and certain others were given a range in classification, as 1 to 2, 2 to 3, or 3 to 4. Two materials were effective for 8 to 12 days (class 3), and 11 caused complete knock-down or kill of lice for 13 or more days (class 4). These 11 compounds were sulfoxide, 1,2-methylenedioxy-4-[2-(octylsulfonyl)propyl]benzene, dibutyl piperonylidene ester of malonic acid, *alpha*-(3-phenylpropyl) piperonyl ester of senecioic acid, and the following esters of chrysanthemumic acid: *alpha*-allylpiperonyl, *alpha*-amylpiperonyl, *alpha*-butylpiperonyl, *alpha-tert*-butylpiperonyl, *alpha*-ethylpiperonyl, *alpha*-(2-methylallyl)piperonyl, and 4-(3,4-methylenedioxyphenyl)-*sec*-butyl.

Some of these synergists and several others have been evaluated in arm and leg tests on research subjects, according to the method of Bushland and coworkers (1944b). A number of the materials appeared about equal to the standard, sulfoxide, but none proved outstandingly more effective. In general, synergized allethrin preparations, whether tested as cloth impregnants or as powders, have not proved as effective against body lice as similar synergized pyrethrum preparations. However, the difference in a small-scale field test (Eddy 1952) was not great.

SUMMARY.—During the period 1951-53 a total of 203 compounds were tested in the laboratory as synergists with allethrin against the body louse, *Pediculus humanus humanus* L. The materials were evaluated as cloth impregnants and in powders prepared with pyrophyllite. As cloth impregnants the minimum lethal concentration and duration of residual effectiveness of the materials were determined. The tests with powders applied to cloth were made from a residual standpoint only. The materials were given class ratings from 1 to 4 (4 being the most effective), based on their effectiveness in the different tests. On the basis of minimum lethal concentration 11 materials proved more efficient as synergists than the standard, sulfoxide. Some of them increased the toxicity of allethrin from 10 to 20 times or more. On a residue basis, both as cloth impregnants and in powders, nine materials appeared about equal to or slightly more effective than sulfoxide. They were 1,2-methylenedioxy-4-[2-(octylsulfonyl)propyl]benzene, dibutyl piperonylidene ester of malonic acid, and the following esters of chrysanthemumic acid: *alpha*-allylpiperonyl, *alpha*-amylpiperonyl, *alpha*-butylpiperonyl, *alpha-tert*-butylpiperonyl, *alpha*-ethylpiperonyl, *alpha*-(2-methylallyl)piperonyl, and 4-(3,4-methylenedioxyphenyl)-*sec*-butyl.

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# The Cholinesterase Systems of Three Species of Fruit Flies and the Effects of Certain Insecticidal Compounds on these Enzymes

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The rate of hydrolysis of acetylcholine (ACh) and acetyl-beta-methyl choline (AMeCh) by cholinesterase (ChE) has been used by Metcalf & March (1950) to indicate differences in the properties of ChE from the heads of honey bee, the mouse, and the house fly. They also observed that the isopropyl homolog of parathion was much less effective in inhibiting honey bee head ChE than it was against house fly head ChE. Babers & Pratt (1951) confirmed the differences between the ChE of bee and fly and indicated that the enzyme from the head of the American cockroach was more nearly like that of the honey bee. Roan & Maeda (1953) observed that the ChE from the head of the oriental fruit fly, *Dacus dorsalis* Hendel, is comparable with that reported by other workers for the house fly, in regard to both substrate specificity and response to a series of organic phosphorus compounds.

Roan & Maeda (1953) also reported that 1-phenyl-3-methyl pyrozolyl-(5)-dimethyl carbamate (compound 22008) has the same order of effectiveness as paraoxon as an inhibitor of oriental fruit fly ChE. Compound 22008 is similar to physostigmine and prostigmine in that it is an alkyl carbamic ester. Stedman (1926) indicated that the methylcarbamic ester group of physostigmine and related compounds are essential for anticholinesterase activity. Aeschlimann & Reinhart (1935) observed that prostigmine, possessing a dimethyl carbamic ester group, is approximately as effective an inhibitor as physostigmine.

It was therefore of interest to extend the previous tudies with the oriental fruit fly to include a series of compounds structurally related to compound 22008 as well as the organic phosphorous compounds, and to investigate the properties of the ChE from the closely related species the melon fly, *Dacus cucurbitae* Coq., and the Mediterranean fruit fly, *Ceratitis capitata* (Wied.). The compounds were investigated both as *in vitro* inhibitors of ChE and as toxicants.

Materials and Methods.—The colorimetric method of Hestrin (1949) for the determination of acetylcholine was used in the *in vitro* investigations. Breis were prepared from the heads of flies of uniform age by grinding them with a Potter-Elvehjem homogenizer in a buffer (0.15M sodium chloride, 0.04M magnesium chloride, 0.025M sodium bicarbonate). The stock solutions of breis contained 1.2 mg. of tissue per milliliter. Substrates were made up in 0.001N sodium acetate and the inhibitors in propylene glycol-acetone (9 to 1) mixtures. The reaction flasks were 20×90 mm. shell vials, to each of which were added 2.6 ml. of tissue brei and 0.1 ml. of inhibitor or distilled water. After thorough mixing of their contents, the reaction flasks were immersed in a 37° C. water bath. The inhibitors were then allowed to incubate with the enzyme preparation for 20 minutes prior to the addition of 0.3 ml. of the substrate. The reaction period was for 30 minutes after the addition of the substrate. At the end of the reaction period three 1-ml. aliquots were taken and the colors were developed by the methods described by Hestrin (1949). One aliquot was employed for a nonspecific color control, and the other two served as replicates. A substrate control was run for each determination. Readings were taken at 540 mμ with a Beckman Model B spectrophotometer.

In the tests to determine the optimum substrate concentration for the three species of flies, it was found impractical to vary the substrate concentrations over the entire range required, owing to limitations of the colorimetric method. Therefore, the concentration of substrate was kept constant at $5\times10^{-3}$M, and the amount of tissue brei was varied to give different enzyme/substrate ratios (E/S). It was assumed that the amount of enzyme present would be directly related to the amount of tissue. The relation of the S/E ratios reported here to the pS

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values is shown in table 1.

Dosage-mortality data were obtained from topical applications of acetone solutions of the selected toxicants to the venter of the thorax of flies of uniform age. The applications were made with the micropipette described by Roan & Maeda (1953). The per cent mortality at 24 hours was plotted against the dosage on log-probit paper and the LD-50's were determined directly from such plots.

**Table 1.—Amounts of substrate (S)[1] and enzyme (E)[2] used for the manometric and colorimetric determinations of the effect of substrate concentration on the rate of hydrolysis of ACh by the ChE of the oriental fruit fly.**

| MANOMETRIC (E=3.12)[3] | | COLORIMETRIC (S=5)[4] | |
|---|---|---|---|
| $pS^{5}$ | S | S/E | E |
| 0.82 | 450 | 144 | — |
| 1.11 | 225 | 72 | — |
| 1.49 | 97 | 31 | 0.16 |
| 1.79 | 49 | 15.6 | 0.32 |
| 2.05 | 27 | 8.6 | 0.58 |
| 2.37 | 13 | 4.15 | 1.2 |
| 2.64 | 7 | 2.24 | 2.2 |
| 2.90 | 3.5 | 1.13 | 4.4 |
| 3.30 | 1.5 | 0.48 | 10.4 |

[1] Substrate concentrations expressed as micromoles per test.
[2] Enzyme concentrations expressed as milligrams of brain brei per test.
[3] Test solutions made up to 3 ml.
[4] Test solutions made up to 1 ml.
[5] Log 1/S, where S is expressed in final molar concentration.

SUBSTRATE SPECIFICITY.—Roan & Maeda (1953) indicated that the ChE of the oriental fruit fly appeared to be similar to that reported by Metcalf & March (1950) for the house fly. In figure 1, where the log of the S/E ratio is plotted against activity for the ChE of the oriental fruit fly, an optimum of S/E 8.6 is indicated. Reference to table 1 indicates good agreement with the previously indicated optimum of pS 2.1. Figures 2 and 3 present the data obtained with the ChE from the Mediterranean fruit fly and the melon fly. The optima occur within the range indicated for the oriental fruit fly for the hydrolysis of ACh, and the shape of the curves for both ACh and AMeCh suggests that the enzyme for all three species of flies is specific for ACh in a manner similar to that reported by Metcalf & March (1950) for the house fly. The data for the maximum velocity ($V_{max}$) and dissociation constant ($K_s$) as determined by the graphical method of Lineweaver & Burk (1934), in table 2 also indicate a similarity in these enzymes, particularly as contrasted with the data reported for the bee by Metcalf & March (1950).

**Table 2.—Theoretical maximum velocities ($V_{max}$) and dissociation constants ($K_s$) of the enzyme-substrate complex for the ChE of the oriental fruit fly, the melon fly, and the Mediterranean fruit fly.**

| INSECT | ACh | | AMeCh | |
|---|---|---|---|---|
| | $V_{max}$ | $K_s$ | $V_{max}$ | $K_s$ |
| Oriental fruit fly | 1.60 | $7.6\times10^{-4}$ | 0.7 | $2.3\times10^{-2}$ |
| Melon fly | 1.54 | $8.1\times10^{-4}$ | 0.5 | $8.9\times10^{-2}$ |
| Mediterranean fruit fly | 1.64 | $8.8\times10^{-4}$ | 1.1 | $2.9\times10^{-2}$ |

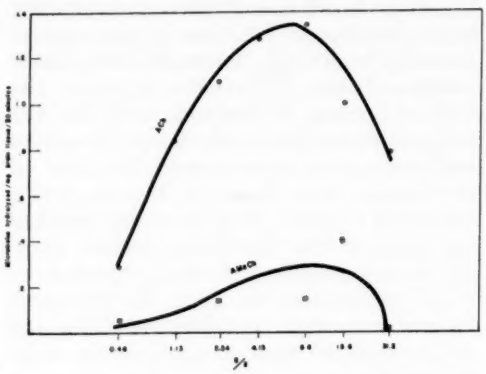



FIG. 1.—The effects of substrate concentration on the rate of hydrolysis of ACh and AMeCh by the ChE of the brain of the oriental fruit fly.

*In Vitro* REACTION OF CHOLINESTERASES WITH INSECTICIDAL COMPOUNDS.—The concentrations of 22 compounds, representing two classes of chemicals, required to inhibit 50 per cent ($IN_{50}$) of the ChE of the three species of fruit flies studied were determined by plotting the

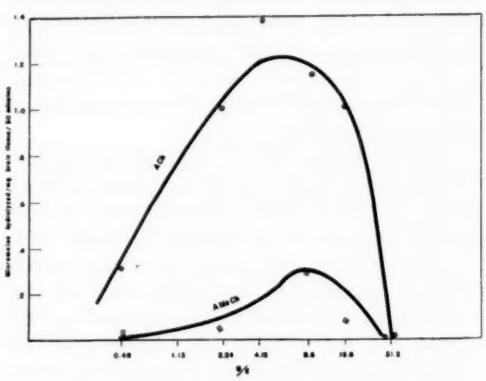
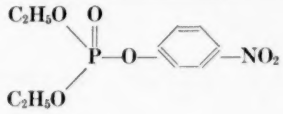
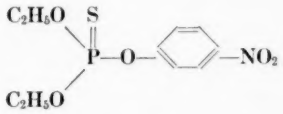
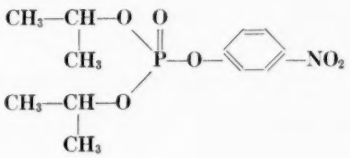
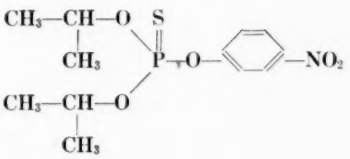
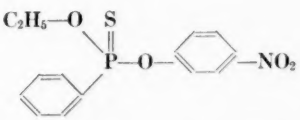
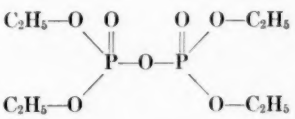
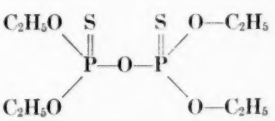
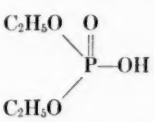
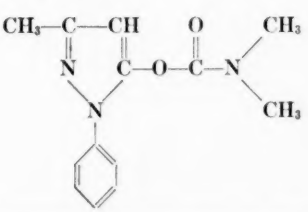
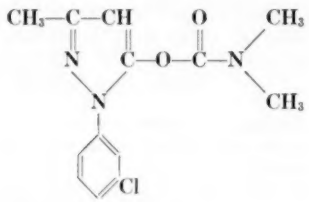
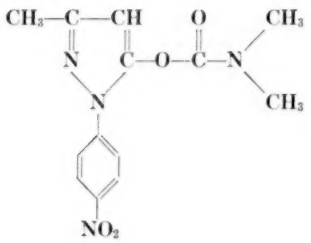
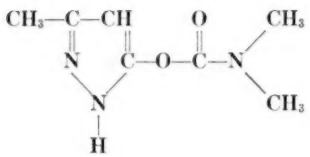
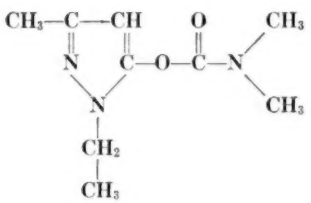
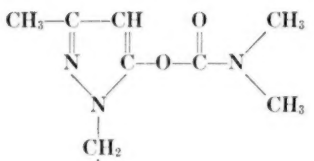
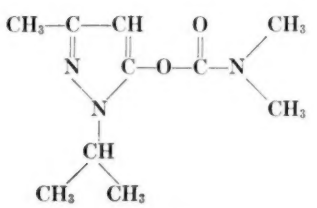
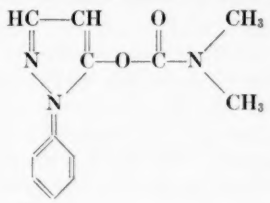
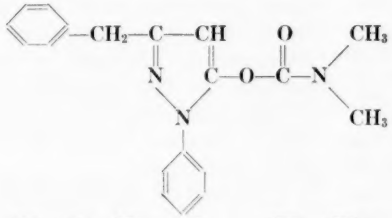
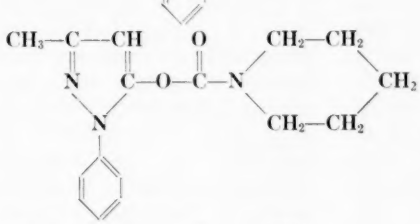
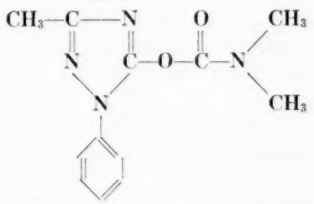
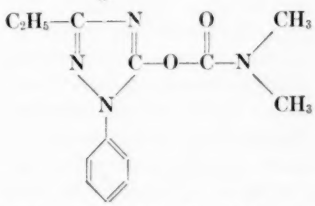
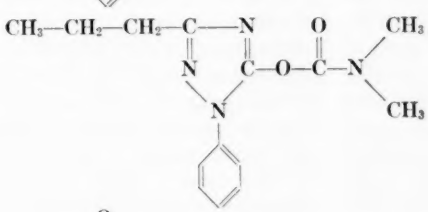
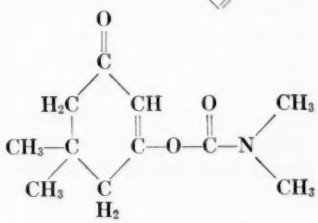



FIG. 2.—The effects of substrate concentration on the rate of hydrolysis of ACh and AMeCh by the ChE of the brain of the melon fly.

**Table 3.—Inhibition of oriental fruit fly, melon fly, and Mediterranean fruit fly brain cholinesterase by certain organic insecticidal compounds.**

| COMPOUND | FORMULA | FINAL MOLAR CONCENTRATION FOR $IN_{50}$ | | |
|---|---|---|---|---|
| | | Oriental Fruit Fly | Melon Fly | Mediterranean Fruit Fly |
| Para-oxon |  | $9\times10^{-9}$ | $8.8\times10^{-9}$ | $1\times10^{-8}$ |
| Parathion |  | $2.3\times10^{-7}$ | $8.6\times10^{-8}$ | $1\times10^{-7}$ |
| Diisopropyl para-oxon |  | $1.5\times10^{-8}$ | $1.8\times10^{-8}$ | $1.3\times10^{-8}$ |
| Diisopropyl parathion |  | $3\times10^{-6}$ | $3\times10^{-6}$ | $4\times10^{-6}$ |
| EPN |  | $4\times10^{-6}$ | $3.6\times10^{-6}$ | $3.2\times10^{-6}$ |
| TEPP |  | $7.5\times10^{-10}$ | $7.2\times10^{-10}$ | $7\times10^{-10}$ |
| Sulfotepp |  | $5.2\times10^{-8}$ | $1.2\times10^{-8}$ | $7.6\times10^{-8}$ |
| Diethyl phosphoric acid |  | $2.4\times10^{-5}$ | $2.8\times10^{-5}$ | $2.6\times10^{-5}$ |
| 22008 |  | $2\times10^{-8}$ | $7.8\times10^{-8}$ | $2.8\times10^{-8}$ |

| Compound | Formula | Final Molar Concentration for $IN_{50}$ | | |
|---|---|---|---|---|
| | | Oriental Fruit Fly | Melon Fly | Mediterranean Fruit Fly |
| 22419 |  | $1.8\times10^{-8}$ | $4.8\times10^{-8}$ | $3\times10^{-8}$ |
| 23327 |  | $4.6\times10^{-8}$ | $2.7\times10^{-8}$ | $2.6\times10^{-8}$ |
| 22870 |  | $5\times10^{-7}$ | $5.4\times10^{-7}$ | $7.8\times10^{-7}$ |
| 23224 |  | $1.4\times10^{-7}$ | $2.3\times10^{-7}$ | $2.2\times10^{-7}$ |
| 23842 |  | $1.4\times10^{-7}$ | $1.4\times10^{-7}$ | $3.3\times10^{-7}$ |
| 23611 |  | $7.2\times10^{-8}$ | $8\times10^{-8}$ | $1.2\times10^{-7}$ |

| COMPOUND | FORMULA | FINAL MOLAR CONCENTRATION FOR $IN_{50}$ | | |
|---|---|---|---|---|
| | | Oriental Fruit Fly | Melon Fly | Mediterranean Fruit Fly |
| 23165 |  | $4.6\times10^{-8}$ | $8.6\times10^{-8}$ | $2.7\times10^{-7}$ |
| 23012 |  | $3.7\times10^{-8}$ | $4\times10^{-9}$ | $4.2\times10^{-8}$ |
| 23328 |  | $9.2\times10^{-8}$ | $5.4\times10^{-8}$ | $9\times10^{-8}$ |
| 23162 |  | $9.2\times10^{-6}$ | $8.2\times10^{-6}$ | $8.4\times10^{-6}$ |
| 23341 |  | $2\times10^{-7}$ | $3.4\times10^{-7}$ | $3.4\times10^{-7}$ |
| 23164 |  | $8\times10^{-6}$ | $6.4\times10^{-6}$ | $6.2\times10^{-6}$ |
| 19258 |  | $5\times10^{-7}$ | $6.5\times10^{-7}$ | $5.6\times10^{-7}$ |

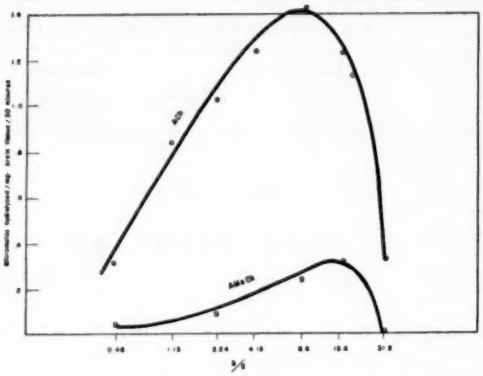


FIG. 3.—The effects of substrate concentration on the rate of hydrolysis of ACh and AMeCh by the ChE of the brain of the Mediterranean fruit fly.

probit of per cent inhibition against the log of the concentration. The values given in table 3 are the final molar concentrations in the reaction flasks. These data indicate only minor differences in the *in vitro* response of the ChE of the three species with respect to changes in the chemical molecules. The anticholinesterase actions of the organic phosphorus compounds with the ChE of the Mediterranean fruit fly and the melon fly are comparable with those reported by Roan & Maeda (1953) for the oriental fruit fly. The carbamates represent another type of potential insecticide that is capable of inhibiting ChE. The *in vitro* data for these compounds in table 3 indicate similar reactions with the ChE from the three species of flies investigated. This is further evidence of the similarity of the ChE from these test organisms.

The effect of alterations of the chemical molecules on their anticholinesterase activity is also of interest. The effects of structural changes in the organic phosphorus compounds have already been discussed by Metcalf & March (1949, 1950) for the house fly, the bee, and the mouse. Roan & Maeda (1953) reported similar observations for the oriental fruit fly, and the data reported in this paper indicate the same trend for the Mediterranean fruit fly and the melon fly. The only phosphorus compound not reported previously is diethyl phosphoric acid, an expected hydrolysis product of the oxygen analogs. It is of interest to note that it is considerably less effective than TEPP.

With compound 22008 as the basis for comparison, the changes in anticholinesterase activity as the chemical structure is changed are of interest. Starting with the "1" position of the pyrazolyl ring, there are no major changes in such activity until the phenyl group is completely removed, as with compound 22870. Compound 23611, with the isopropyl group, has nearly the same activity as compound 22008. Compounds 23165 and 23012 represent changes in the group on the "3" position of the pyrazolyl ring. Neither the removal of the methyl group nor the substitution of the benzyl group appears to have any great effect on the *in vitro* activity. The only compound in this series representing changes in the carbamate portion of the molecule is compound 23328, a pentamethylene carbamate ester, which does not appear to change the activity materially.

Compounds 23162, 23341, and 23164 have a triazolyl ring instead of the pyrazolyl ring and are generally less effective as *in vitro* ChE inhibitors. Compound 23341, with the 3-ethyl group, appears to be more effective than either the 3-methyl or the 3-propyl compound. Compound 19258, (4,4-dimethyl-2-cyclohexenyl, 3-dimethyl-carbamate) represents the most drastic change in this series. It appears to be about as effective an *in vitro* inhibitor as the triazolyl compounds.

TOXICITY.—The toxic effects of eight representative compounds on the three species of flies were investigated by making topical applications of acetone solutions of these materials. The compounds were selected to represent the organic phosphorus compounds and the carbamic esters with certain structural variations. These data, as presented in table 4, indicate considerable variation in the effectiveness. Although the *in vitro* actions of these compounds against the ChE of the three species of flies were similar and indicated a further similarity in the nature of the enzyme, the data in table 4 indicate a species differentiation that could not be predicted from the *in vitro* data.

The data in table 3 indicate that compound 22870 is less effective *in vitro* than compound 22008. The toxicity data in table 4 however, show that the first compound is more toxic. The response to *in vitro* inhibition by compound 22008 was very similar for the three species, and even closer agreement was obtained for 22870.

The least effective member of this series from the standpoint of all three species was 23162 which differs from 22008 by having a triazolyl ring in place of a pyrazolyl ring. For the oriental fruit fly 1300 times as much of the triazolyl compound was required for comparable toxicity, but for *in vitro* action the factor was only 20. For the Mediterranean fruit fly the factor for comparable toxicity was 20 and that for *in vitro* action 30. These data, indicating the differences between *in vitro* inhibition and toxicity, suggest that the actions of various other biochemical systems of the organism with the different chemical structures are perhaps not qualitatively similar and certainly not quantitatively comparable.

**Table 4.—Lethal effect of certain insecticidal materials on the oriental fruit fly, the melon fly, and the Mediterranean fruit fly.**

| Compound | $LD_{50}$ (Micrograms/Gram of Body Weight) | | |
|---|---|---|---|
| | Oriental Fruit Fly | Melon Fly | Mediterranean Fruit Fly |
| Para-oxon | 0.37 | 0.53 | 0.23 |
| 22008 | 1.31 | 1.20 | 4.60 |
| 22870 | 0.62 | 0.80 | 1.97 |
| 23012 | 96 | 14 | 1.81 |
| 23328 | 200 | 144 | 30 |
| 23162 | 1720 | 288 | 96 |
| 19258 | 117 | 128 | 92 |

Two of these compounds, 23012 and 23162, show a marked difference in their toxic effects on the three species of flies (table 4). About 48 times as much 23012 is required for comparable mortality of the oriental fruit fly as for the Mediterranean fruit fly, while for 23162 the factor is 17. With these two compounds the effects on the melon fly are intermediate between the other two species. The differences between the species for the other compounds in this series are much less pronounced but are in general greater than was observed for their *in vitro* effects.

SUMMARY AND CONCLUSIONS.—The effects of the concentrations of the substrates acetyl choline (ACh) and acetyl-beta-methyl choline (AMeCh) on their rate of hydrolysis by the cholinesterase (ChE) of the oriental fruit fly, *Dacus dorsalis*, Hendel the melon fly, *Dacus cucurbitae* Coq., and the Mediterranean fruit fly, *Ceratitis capitata* (Wied.), were investigated by varying the amount of enzyme instead of the amount of substrate in order to overcome limitations of colorimetric procedures. The theoretical maximum velocities ($V_{max}$) and dissociation constants ($K_s$) for the reaction between these substrates and the ChE of these insects were determined by the graphical method of Lineweaver & Burk (1934). The concentrations for 22 compounds, representing both organic phosphorus compounds and alkyl carbamic esters, required to inhibit 50 per cent of the cholinesterase of these insects under *in vitro* conditions were determined and contrasted with the lethal action of selected compounds on the three species of insects.

The results of these investigations indicate that the enzyme in all three species is specific for acetyl choline. The curves for the hydrolysis of these substrates indicate similar maxima, and the data for the theoretical maximum velocities and dissociation constants are of the same order for all three species. These data, together with the *in vitro* reactions of these enzymes with the compounds investigated, indicate that the behavior of these enzymes is very similar. However, a comparison of the *in vitro* data and the toxicity data for eight compounds suggests that other factors may be of considerable importance in the *in vivo* reactions of these compounds. The differences observed in the toxic action of certain of these compounds for the three species suggest that their biochemistry differs considerably even though the *in vitro* action was of the same order for the different organisms.

ACKNOWLEDGEMENTS.—Para-oxon, parathion, diisopropyl para-oxon, and sulfotepp were supplied by the Victor Chemical Works, diisopropyl parathion by the American Cyanamid Company, and numbered compounds in the carbamate series by the Geigy Company. Diethyl phosphonic acid was prepared by chemists in the Bureau of Entomology and Plant Quarantine.

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# Radiophosphorus in Metabolism Studies in the Two-spotted Spider Mite[1]

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Studies dealing with the mineral nutrition of the two-spotted spider mite, *Tetranychus bimaculatus* Harvey, demonstrated that a positive correlation existed between phosphorus content of tomato foliage and the number of mite progeny that developed thereon when phosphorus ranged from a trace to approximately 0.3 per cent, dry weight, of the tomato foliage (Rodriguez 1951). Since this range of phosphorus is common in the host plants of this mite, and since phosphorus assumes such an important role in the nutrition of this mite, it was deemed desirable to attempt to achieve a better understanding of phosphorus turnover in the female mite.

EXPERIMENTAL.—The objectives, briefly, were to determine phosphorus uptake and phosphorus utilization in the female mite at various time intervals, by employing as many radioactive individuals as possible but not sacrificing accuracy for numbers. The fact that plant-feeding mites can readily be made radioactive has been demonstrated (Rodriguez 1948).

Six bean plants of a big-leaf variety (Horticultural Dwarf) were grown under balanced artificial lights (1000 foot candles, 16 hours photoperiod) in artificial culture in each of two 1-gallon battery jars in the laboratory. Three liters of Hoagland's (1950) solution culture[2] were used per jar; iron was furnished in the form of Sequestrene NaFe[3] at the rate of 10 parts per million. When the plants were still in the primary leaf stage, 15 millicuries of $P^{32}$ were introduced as $PO_4$ in weak HCl to one of the jars. Radioactivity of bean foliage, as determined by a portable survey meter, was considered at a maximum 5 days after $P^{32}$ introduction and the primary leaves were detached from all of the plants at this time, and placed in water in individual beakers.

In order to ascertain phosphorus uptake in the mite, an average of 30 young adult (approximately 1 day old) mites were individually selected and introduced in groups of five to ten to radioactive leaf discs. The discs, having been stamped from the primary leaves, were 40 mm. in diameter and had an average specific activity (counts per minute per gram of phosphorus) of $59.6 \times 10^8$; they were floated in petri dishes in a substrate containing 2 per cent sucrose solution as in a method previously reported (Rodriguez 1953). Temperature was maintained at 26° C. $\pm$ 1 and balanced lighting was continuous at 300 candlepower. After feeding on radioactive leaf discs for the prescribed amount of time, about two-thirds of the mites were removed and placed in cupped nickel-plated planchets which contained a drop of mineral oil, in preparation for activity counting. The remainder of the mites were introduced to a non-active leaf disc and allowed to feed for 2 hours; at the

[1] The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director.
[2] Solution No. 1, p. 31.
[3] Geigy Company.

end of this time the mites and eggs (1 egg per mite was common) were also collected and placed in cupped planchets for counting. Because handling was time-consuming it was often desirable to inactivate the mites at the end of a feeding period; the petri dishes containing the mites were refrigerated to accomplish this.

For the phosphorus utilization phase of the experiment, mites were made radioactive by being allowed to feed on detached leaves for 36 hours; at the end of this time they were divided into lots as in the uptake phase of the experiment and transferred to individual non-radioactive leaf discs. At the end of any measured period of feeding, about two-thirds of the mites were again collected for counting while the remaining number were transferred to a second non-radioactive leaf disc, where they were allowed to feed for 2 hours. At the end of this time the eggs were collected and placed in cupped planchets in preparation for counting; the leaf discs with secretions or excretions left behind by the mites were semi-dried and also placed in cupped planchets.

Counts were taken with a shielded, end-window Geiger-Mueller tube with a thickness of 1.9 milligrams per square centimeter and a background of $25 \pm 2$ cpm Virtually all of the samples of mites were counted within 1 per cent standard error; samples of eggs or foliage were of lower activity, however, and standard error here ranged from 2 to 4 per cent. Counts were corrected for coincidence loss, decay and background, and were finally expressed as counts per minute (cpm) per unit. A corollary test to determine egg production and mite longevity was also made under continuous lighting, utilizing non-radioactive leaf discs to culture the mites. Twenty newly-molted females were transferred to individual leaf discs and these were then transferred every 24 hours to new discs and the eggs counted.

RESULTS AND DISCUSSION.—Phosphorus was taken into the body of the mite quite rapidly, as witnessed by the fact that almost half of the acquired phosphorus was ingested in the first 8 hours of feeding (Fig. 1). At least 36 hours were required, however, for the female mite to approximate full phosphorus capacity (2007 cpm). Phosphorus uptake after 24 hours (2-day old adult mites) was

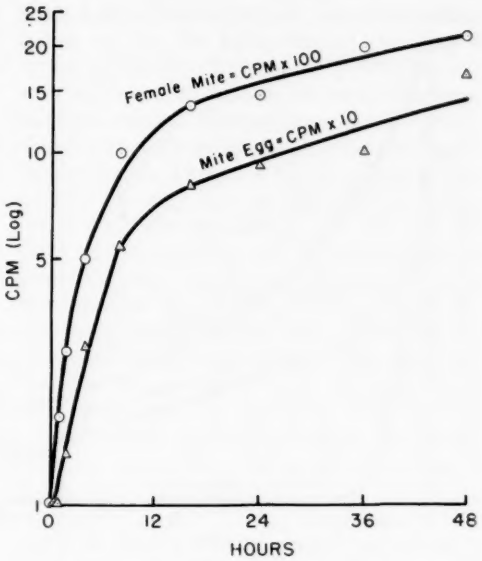


FIG. 1.—Relationship of $P^{32}$ uptake in the female mite body and the egg as evident when activity (counts per minute) is plotted against time.

relatively slow and accumulation occurring after this period is probably due to growth or expansion of this soft-bodied species. The phosphorus uptake of the eggs laid during this period was shown to be an approximate constant with the phosphorus uptake of the female mite (Fig. 1). At 36 hours the activity reached 107 cpm per egg.

Phosphorus was utilized rapidly but the rate of utilization of the mite *per se* was less than the rate of uptake since about half of the ingested phosphorus was utilized 20 hours after ingestion and the cpm per mite was 1082 (Fig. 2). This is further proof that a laying down of tissue occurred in the young female after the last molt; moreover, an apparent increase in size was observed as mites aged. It follows that eggs produced by the older mites tend to be somewhat larger than by younger females and this is further evidenced by higher counts on the eggs as the mites aged.

A comparatively large amount of phosphorus goes into egg production (activity was 115 cpm per egg at the beginning of the utilization phase); apparently phosphorus compounds going into egg-production are characterized by a rapid phosphorus turnover since the rate of utilization for the eggs is unlike the rate apparent in the

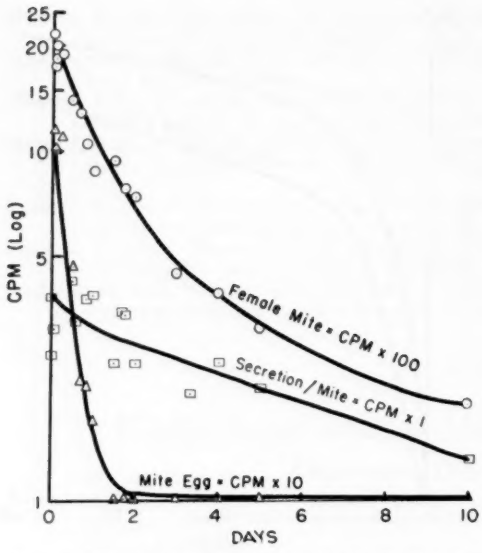


FIG. 2.—Relationship of $P^{32}$ utilization in the female mite body and some of its processes as evident when activity (counts per minute) is plotted against time.

mite *per se* (Fig. 2). Hence, in the egg, the curves demonstrate that the rate of phosphorus uptake and the rate of utilization are virtually the same. Egg production, then, consumes relatively large quantities of phosphorus.

In the corollary test to investigate egg production and longevity, it was found that female mites cultured under the conditions of this test lived an average of 10.85 days and laid an average of 112.5 eggs per individual during their lifetime. Maximum longevity was 21 days and the maximum number of eggs laid by one female during a 24 hour period was 20, and the maximum total number of eggs laid by a female was 184. The over-all daily average per mite was 10.3 eggs. Egg-laying was negligible for the 24-hour period following the last molt but increased sharply to an average of 11.1 eggs laid per individual during the second day and reached a maximum of 16.6 eggs per individual during the fifth day.

The method of culture used in these experiments entailed almost a total enclosure of petri dishes with resulting high humidity, which may have increased longevity and total egg production, although the study of Cagel (1949) showed that under his insectary conditions the average length of life for nine broods 1 year was 20.1 days; the total number of eggs laid by these same individuals averaged 62.1.

It is of interest that the unit volume concentration of phosphorus in the egg was approximately three times that in the body of the mite. The female mite approximates an object prolate spheroid in shape, 0.500 mm. in length and 0.300 mm. in width, while its egg approximates a sphere 0.100 mm. in diameter. The ratio of the unit volume mite to egg equals about 45:1, while the ratio of phosphorus in the mite to phosphorus in the egg, per unit, is 15:1. It follows that phosphorus turnover is rapid when as many as 20 eggs per day are laid by a female. It is to be regretted that chemical analyses of mites and eggs could not be made and their specific activity could not be obtained. Availability of these data probably would have assisted in explaining and corroborating the causes behind the rapid disappearance of phosphorus in the first 2 days of the utilization phase of the study.

SECRETIONS AND EXCRETIONS.—Other aspects of phosphorus utilization can be considered as parts of the processs of secretion and excretion (Fig. 2). In previous work (unpublished) the author observed that mites were apparently introducing a phosphorus-containing secretion into the leaf tissue while feeding; this material was also found to be translocated within the plant. Blauvelt (1945) noted that the unpaired tracheal salivary gland discharged onto the upper surface of the stylets. Since the stylets are moved vigorously up and down in puncturing the plant tissue when feeding, it would seem logical that the secretion would flow along the stylets and would inevitably be introduced into the puncture. At any rate, the phosphorus-containing secretions absorbed by the foliage of bean plants were translocated to other parts of plants. It has not been possible to determine how much phosphorus is utilized in secretion, since fecal pellets are covered with a film of fluid when voided which may be absorbed by the leaf and this factor is likely to be a source of contamination; however, excretion was not considered a separate phase of these studies since it was not feasible to separate and transfer fecal pellets from the leaf to the counting planchet. Nevertheless, it was assumed that once the in-

gested radioactive plant material was excreted, further excretion would produce relatively little labelled phosphorus. The fact that the "secretion" curve levels off after the first day adds substance to this assumption (Fig. 2). The possible detrimental effects of the secretion on leaf tissue have not been determined. Such a possibility has been considered by some workers; Schread (1953) noted that mites may inject a toxic substance when feeding. It is of further interest that phosphorus is apparently utilized by the salivary gland at a rate quite unlike that of the egg and mite body, since the activity evident in secretions left on leaf discs showed a relatively gradual change in rate between the first and tenth day (Fig. 2).

Another secretion which is likely to contain phosphorus is that of the silk glands, of which there are two pairs in this species (Blauvelt 1945, Snodgrass 1948). The process of spinning appears to be a behavior which is particularly apparent when food becomes scarce and the urge to move seemingly activates the silk-spinning process.

SUMMARY.—Studies on phosphorus metabolism in the two-spotted spider mite were made by allowing young adult female mites to feed on radioactive bean leaves. Radioactivity of mites and eggs was determined at intervals over a period of 48 hours to determine phosphorus uptake. Radioactive mites were transferred to non-active leaf discs and activity of mites, eggs and discs was determined at intervals over a period of 10 days to determine phosphorus utilization. Almost half of the acquired phosphorus was taken up by the mite during the first 8 hours of feeding; full capacity (2007 cpm) was achieved at about 36 hours but uptake proceeded thereafter at a slow rate, due to growth or expansion of this soft-bodied mite. The rate of phosphorus uptake in the egg was an approximate constant with the uptake in the mite *per se* (107 cpm maximum). Utilization of phosphorus in egg production proceeded at a rate similar to uptake; however, utilization in the mite body was much slower, since about 20 hours were required for half the phosphorus to be utilized. This change of rate is probably due to the growth factor as the mite ages. Since the ratio of the unit volume mite to egg is 45:1 and phosphorus in mite to phosphorus in egg was 15:1, phosphorus in the egg was three times as concentrated as in the mite body. Mites in a corollary experiment to determine egg production and longevity laid a maximum daily average of 16.6 eggs during the fifth day; the mites lived an average of 10.85 days and laid an average of 10.3 eggs per day during this time. Egg production, therefore, consumes relatively large quantities of phosphorus. Non-radioactive leaf discs became radioactive when fed on by radioactive mites, showing that a secretion containing phosphorus, thought to originate in the tracheal salivary gland, was injected into the leaf. Although this material was introduced into the plant, the possibility of the secretion being toxic to the plant system was not investigated.

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# Control of the Cranberry Fruitworm on Blueberries[1]

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The cranberry fruitworm, *Mineola vaccinii* (Riley) has been a serious pest of cranberries in the United States since before 1900. Smith (1905) describes the life cycle, and Franklin (1948) notes that the insect causes severe damage to cranberries in Massachusetts and Wisconsin. Although of lesser importance in New Jersey, Oregon and Washington, it can be destructive in these areas. The first record of *Mineola* as a pest of blueberries occurs in reports of Beckwith to the New Jersey Agricultural Experiment Station in 1935. Since that time, it has also been reported as being an occasionally serious pest of cultivated blueberries in Michigan (Hutson 1944) and North Carolina (Fulton 1946). In all locations, the abundance of this insect has been reported as being cyclical, indicating control by natural enemies.

LIFE CYCLE.—In New Jersey blueberry fields, the mature larvae overwinter in the soil to a depth of 1 inch. By careful screening of soil P. E. Marucci (unpublished data, 1952–53) recovered large numbers of the sand-coated hibernacula. He found that the larvae pupate the following spring and that the moths emerge over a period of about 2 weeks, beginning the third week in May. The plastic, yellow eggs are laid on the green berries, principally within the calyx cup, and the larvae hatch in 4 to 5 days. The peak of oviposition occurs within the first 2 weeks, with a smaller number of eggs being laid up until the eighth week. Larval entry into the berries is not immediate, but once having penetrated, the feeding larvae pass from berry to berry, webbing together as many as a dozen. Infested berries color sooner than uninfested berries and ultimately shrivel. The crop is therefore damaged not only by the presence of larvae, but also by the frassy, dried up berries that hinder picking. Crop losses can be nearly complete, although this is quite uncommon. Early varieties of blueberries are principally affected.

Only one generation per year has been noted. This implies that the activity of the fruitworm may be delayed on cranberry bogs by the winter flooding, since green cranberries are not produced until the middle of July, whereas green blueberries are present in late May. Smith (1905) outlines the life cycle in New Jersey, and Franklin (1948) reviews the life cycle on Massachusetts cranberry bogs and includes excellent photographs.

Host plants of this insect in the wild are reported as being cranberries, blueberries and huckleberries (*Gaylussacia* spp.). These appear to act as sources of reinfestation for blueberry fields and cranberry bogs.

CONTROL MEASURES.—Control measures were first applied against this insect on cranberry. Smith (1905) recommended flooding cranberry bogs just after harvest, when the larvae were most susceptible. Pyrethrum was found to be moderately effective against the fruitworm on cranberry (Franklin 1937) and by Beckwith (1941) on blueberry. In 1946, Fulton found both cryolite and DDT to be effective on blueberry. However, cryolite caused some plant injury. Berry (1950) reported that ryania was more effective than cryolite on cranberry, and in 1951, Tomlinson recommended methoxychlor for control of this insect on blueberry.

*Experiments in 1953.*—A three acre blueberry field at Lower Bank, N. J., that had been heavily infested with cranberry fruitworm during the 1952 season, was chosen for this work. The infestation was especially heavy because the field was maintained in sod instead of being cultivated, which left the overwintering larvae undisturbed.

Ten spray treatments were used, and were randomized within each of three adjoining rows of 6-year-old blueberry bushes of the Cabot variety. Five bushes were used in each plot. Four applications were made at 4 to 6 day intervals, beginning immediately after the first eggs hatched. As shown in table 1, the infestation in the untreated plots was such that the berries were worthless at both first and second pickings. Malathion and

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, Rutgers University, The State University of New Jersey, Department of Entomology.

**Table 1.—Insecticides for control of the cranberry fruitworm.[1]**

| TREATMENT | POUNDS OF AND PER CENT WETTABLE POWDER USED PER 100 GAL. | REPLICATE 1 | | REPLICATE 2 | | REPLICATE 3 | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|
| | | Larvae | Frassy Clusters | Larvae | Frassy Clusters[2] | Larvae | Frassy Clusters[2] | Larvae | Frassy Clusters[2] |
| DDT | 2, 50 | 0 | 2 | 4 | 4 | 1 | 3 | 5 | 9 |
| TDE | 2, 50 | 1 | 6 | 4 | 4 | 0 | 2 | 5 | 12 |
| Q-137 | 2, 50 | 4 | 10 | 6 | 7 | 2 | 15 | 12 | 32 |
| Methoxychlor | 3, 50 | 1 | 1 | 0 | 2 | 0 | 0 | 1 | 3 |
| Lindane | 1, 25 | 8 | 29 | 9 | 30 | 21 | 40 | 38 | 99 |
| Endrin | [3] | 0 | 1 | 0 | 3 | 0 | 3 | 0 | 7 |
| Ryania | 7, 96-3 | 9 | 6 | 24 | 20 | 13 | 9 | 46 | 35 |
| Parathion | 1.5, 15 | 1 | 2 | 0 | 3 | 0 | 2 | 1 | 7 |
| EPN | 1.5, 27 | 0 | 17 | 2 | 10 | 2 | 5 | 4 | 32 |
| Malathion | 2, 25 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 2 |
| Untreated | first picking 6/26 | 10 | 70 | 28 | 54 | 21 | 42 | 59 | 166 |
| | second picking 7/3 | 34 | 72 | 16 | 62 | 8 | 12 | 58 | 146 |

[1] Plants of Cabot variety; 5 plants per plot. Sprays applied May 27, June 2, June 8 and June 12 to run-off. A one-quart sample of ripe berries was taken for evaluation from each replicate, with an average of from 800–1000 berries per quart. Treatments were sampled on 6/26.
[2] 3–12 berries per cluster.
[3] Used 1 pint of 19 per cent emulsion concentrate.

methoxychlor gave nearly complete protection. This was especially evident, since in all cases the malathion plots were adjacent to the untreated plots. Parathion and endrin also gave excellent protection. DDT was somewhat less satisfactory, and ryania was relatively ineffective. Most of the larvae from the ryania plots were alive 2 weeks after the samples were taken, although their ability to feed upon treated berries appears to have been impaired.

Analyses of toxicant residues remaining on the berries at harvest (Table 2) were made by Dr. Joseph M. Ginsburg of the New Jersey Experiment Station. Residues of Q-137, endrin and ryania were not analyzed because adequate methods were not available. Although heavier than normal rainfall occurred prior to the first picking, the large number of applications allowed considerable accumulation of residue. Under conditions of actual grower usage, no more than two applications would be used. The sharp drop in residue found a week later at the second picking probably reflects the dilution of sprayed

**Table 2.—Insecticide residues recovered from blueberries treated for control of the cranberry fruitworm.**

| TOXICANT | POUNDS OF AND PER CENT WETTABLE POWDER USED PER 100 GAL. | DATES HARVESTED | TOTAL RAIN INCHES[1] | RESIDUES P. P. M. |
|---|---|---|---|---|
| DDT | 2, 50 | 6/26 | 3.71 | 13.12 |
| | | 7/3 | 3.74 | 6.86 |
| TDE | 2, 50 | 6/26 | 3.71 | 15.10 |
| | | 7/3 | 3.74 | 7.10 |
| Methoxychlor | 3, 50 | 6/26 | 3.71 | 18.86 |
| | | 7/3 | 3.74 | 11.34 |
| Parathion | 1.5, 15 | 6/26 | 3.71 | 0.05 |
| | | 7/3 | 3.74 | 0.0 |
| EPN | 1.5, 27 | 6/26 | 3.71 | 0.30 |
| | | 7/3 | 3.74 | 0.22 |
| Malathion | 2, 25 | 6/26 | 3.71 | 0.0 |
| Lindane | 1, 25 | 6/26 | 3.71 | 0.0 |

[1] Recorded 7 miles away at Bass River State Forest as follows: May 30—0.6 inches, May 31—.42 inches, June 1—.40 inches, June 7—.25 inches, June 13—1.24 inches, June 15—.42 inches, June 23—.38 inches, July 2—.03 inches.

**Table 3.—Flavor evaluation of blueberries treated for control of the cranberry fruitworm.**

| TREATMENT | FLAVOR EVALUATION IN RELATION TO THE UNTREATED CHECK | PER CENT ACCEPTABLE RATINGS IN TWO REPLICATED TASTINGS BY 11 JUDGES[1] |
|---|---|---|
| 1. DDT | Different | 70 |
| 2. TDE | Different | 80 |
| 3. Q-137 | Similar | 70 |
| 4. Methoxychlor | Different | 70 |
| 5. Lindane | Different | 70 |
| 6. Endrin | Different | 70 |
| 7. Ryania (coded check) | Different | 85 |
| 8. Parathion | Different | 95 |
| 9. EPN | Different | 75 |
| 10. Malathion | Different | 75 |
| 11. Ryania (uncoded check) | | 100 |

[1] Not to be construed as reflecting general consumer preference.

surface by rapid berry growth, since virtually no rain fell during this period.

Flavor evaluation tests of treated berries (Table 3) were made by members of a trained panel under the leadership of Dr. Walter Maclinn of the Food Technology Department of the New Jersey Experiment Station. The berries had been frozen after harvest and were tested 30 minutes after being removed from the freezer. No untreated berries were included in the tests because the extensive insect damage made them unfit for consumption. Berries from the plots treated with ryania were therefore used in place of untreated berries. Flavor evaluation was made difficult because of maturity differences among berries within individual samples, and because of the toughness of the skins, typical of the Cabot variety of blueberry. The principal finding was that the berries treated with Q-137 had a significantly better panel rating than all other samples, and that the berries treated with methoxychlor had a significantly poorer panel rating than samples 2, 3, 5, 6, 7, 8, 9 and 10.

SUMMARY.—Ten insecticides were tested against the cranberry fruitworm, *Mineola vaccinii* Riley, in a heavily infested blueberry field at Lower Bank, N. J. Malathion, methoxychlor, endrin and parathion gave outstanding control. Treated berries were subjected to residue analyses and flavor evaluation.

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# Seasonal Weather Influence on Efficiency of Systox Applications for Control of Mites on Lemons in Southern California[1]

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Studies by Metcalf & Carlson (1950) and by Jeppson *et al.* (1952) have shown that trunk and foliage applications of octamethyl pyrophosphoramide and of Systox to citrus resulted in high mortalities of citrus red mite, *Metatetranychus citri* (McG.), on fruit and foliage. In continued field studies, however, there was a considerable variation in the effectiveness of applications made at different times of the year. In fact, trunk applications on oranges in January and lemons in January and February, 1952, failed to result in mortality of mites placed on fruit after treatment. Because of the variation in control of citrus red mite and citrus bud mite, *Aceria sheldoni* (Ewing), indicated by these early tests, it seemed advisable to ascertain the degree of efficiency of applications made in different months of the year in an attempt to correlate results with general weather conditions and with plant responses to seasonal variations.

MATERIALS AND METHODS.—The experimental orchard used in this study was located at Escondido, California, and consisted of 12-year-old Lisbon lemon trees on sweet orange rootstock. The grove was heavily infested with citrus bud mite on May 1, 1952, when the experiment was initiated.

Systox was applied at a dosage of 0.5

[1] Paper No. 800, University of California Citrus Experiment Station, Riverside, California.

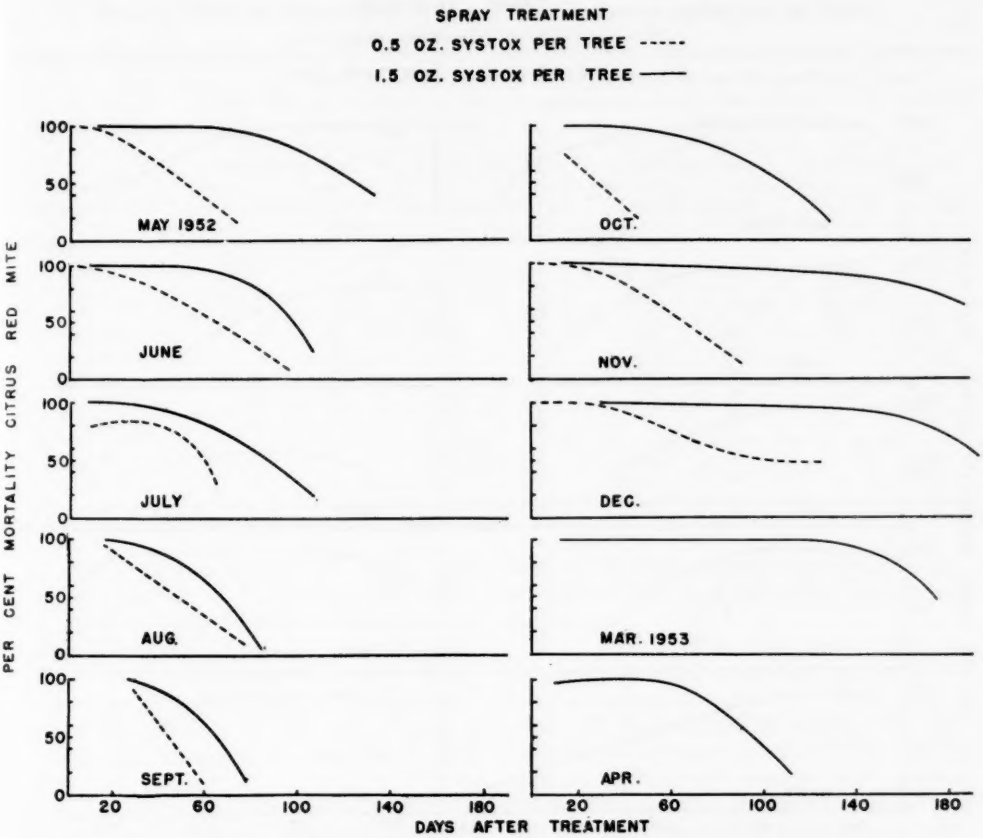


FIG. 1.—Influence of month of treatment on percentage mortality of adult female citrus red mites exposed for 96 hours to lemon fruits picked at intervals after spray applications of Systox at 0.5 and 1.5 ounces of active ingredient per tree. (Sprays applied during the first week of month indicated.)

or 1.5 ounces of active ingredient per tree, and applications were made by three different methods, namely, by foliage spray, trunk treatment, or soil treatment. Single-tree plots were used, and all treatments were replicated four times, with no tree receiving more than one treatment throughout the course of the experiment. Applications were made the first week in each month, from May through December, 1952, and in March and April, 1953.

Systox spray was applied as a full-coverage drench by means of a conventional high-pressure sprayer, with a reciprocating pump and manually operated spray guns. A 4-pounds-per-gallon formulation was applied at 8 or 24 fluid ounces (the amount depending upon the dosage desired) in 100 gallons of water at the rate of approximately 12.5 gallons per tree.

Trunk applications were made by means of a paint brush. A dosage of 1.33 pounds of a 4-pounds-per-gallon formulation[2] of Systox was applied as an 18-inch band around the trunk of the tree. No previous preparation of the trunk was made, except to remove dirt or other obstacles to direct application.

Systox was applied to the soil by emulsifying a 4-pounds-per-gallon formulation in water in a spray tank and applying 150 gallons of the formulation to a basin under the trees, the basin being equal in diameter to the aerial part of the tree.

The relative efficiency of the Systox treatments against citrus red mite was evaluated by picking fruits at approximately 2-week intervals after application and infesting these in the laboratory with 25 adult female citrus red mites for each

[2] Supplied by the Dow Chemical Company, Seal Beach, California.

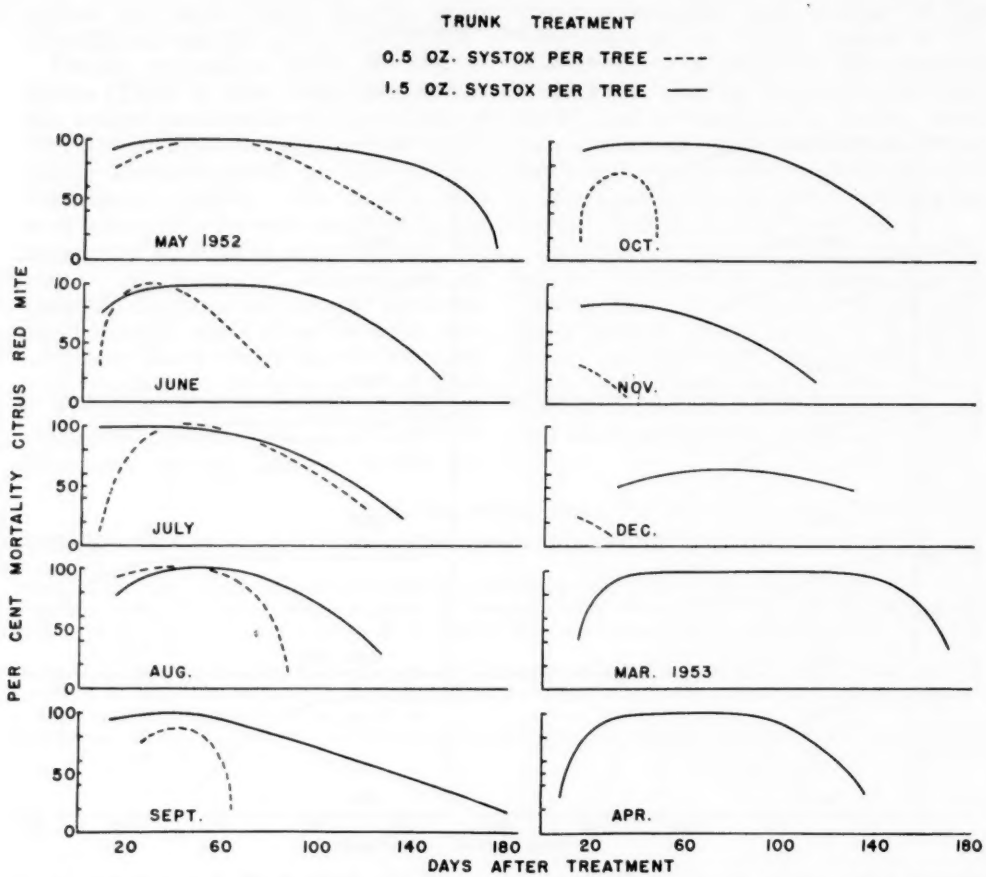


FIG. 2.—Influence of month of treatment on percentage mortality of adult female citrus red mites exposed for 96 hours to lemon fruits picked at intervals after trunk applications of Systox at 0.5 and 1.5 ounces of active ingredient per tree. (Application made during the first week of month indicated.)

of 8 fruits per treatment. The percentage mortality was ascertained after 96 hours' exposure to the treated or check fruit. The effectiveness of the treatment in control of citrus bud mite was evaluated by examining five buds on each of five terminals per tree and ascertaining by means of 20× magnification the percentage of buds infested with live mites.

**Table 1.—Maximum mortalities of citrus red mites exposed for 96 hours to lemon fruits from orchard trees in plots receiving soil applications of Systox.**[1]

| DATE OF APPLICATION OF SYSTOX TO SOIL, 1952 | PER CENT MORTALITY OF MITES AT DIFFERENT DOSAGES | |
|---|---|---|
| | 0.5 Oz./Tree | 1.5 Ozs./Tree |
| May | 27 | 40 |
| June | 24 | 44 |
| July | 7 | 81 |
| August | 6 | 79 |
| September | 13 | 46 |

[1] Fruits picked at approximately 2-week intervals after Systox applications and infested in laboratory with 25 adult female mites for each 98 fruits.

RESULTS.—The results of laboratory assays of the toxicity of fruit from Systox-treated trees to the citrus red mite are shown in figures 1 and 2 and in table 1. Each of the several graphs in figures 1 and 2 represents the mean percentage mortality plotted in relation to the number of days after application that the toxicity of the lemon fruit to citrus red mite was evaluated. Results of spray applications are shown in figure 1 and results of trunk treatments are plotted in figure 2. Maximum mortalities resulting from applications of Systox to the soil from May to September, 1952, are reported in table 1. Because of their relative inefficiency, soil applications were discontinued after the September treatments.

The relative effectiveness of Systox

**Table 2.—Relative effectiveness of Systox trunk and spray applications on lemon trees for control of the citrus bud mite.**

| Date of Application | Per Cent Buds Infested on Two Sampling Dates After Treatment | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Trunk Applications | | | | Spray Applications | | | |
| | 0.5 Ounce/Tree | | 1.5 Ounces/Tree | | 0.5 Ounce/Tree | | 1.5 Ounces/Tree | |
| | 11/18/52 | 7/8/53 | 11/18/52 | 7/8/53 | 11/18/52 | 7/8/53 | 11/18/52 | 7/8/53 |
| 1952 | | | | | | | | |
| May | R T[1] | — | 6 | 54 | R T[1] | — | R T[1] | — |
| June | R T[1] | — | 11 | 47 | R T[1] | — | R T[1] | — |
| July | 14 | 45 | 2 | 48 | R T[1] | — | R T[1] | — |
| August | 9 | 61 | 3 | 37 | 15 | 63 | 17 | 55 |
| September | 7 | 51 | 1 | 20 | 1 | 49 | 2 | 41 |
| October | 11 | 51 | 2 | 55 | 15 | 52 | 0 | 35 |
| November | 61 | 62 | 21 | 50 | 11 | 33 | 4 | 29 |
| December | — | 70 | — | 36 | — | 43 | — | 44 |
| 1953 | | | | | | | | |
| March | — | — | — | 22 | — | — | — | 20 |
| April | — | — | — | 35 | — | — | — | 35 |

[1] "R T" indicates that trees were re-treated before sampling date.

treatments in the control of citrus bud mite, evaluated on November 18, 1952, and again on July 8, 1953, is reported in table 2. This table shows the percentage of buds infested with citrus bud mite when trunk or spray applications of Systox were applied at a dosage of 0.5 or 1.5 ounces per tree during different months of the year.

DISCUSSION.—Results of these studies indicate that seasonal weather changes influence the absorption, translocation, and persistence in toxicity of spray, trunk, and soil applications of Systox. The effects of seasonal weather changes varied with the method of application.

Soil application of Systox resulted in less efficient control of mites than either conventional spray application or trunk treatment regardless of the time of year in which applications were made. Spring and summer conditions appeared to be most favorable for absorption of the toxicants by the roots and translocation to other parts of the tree (Table 1). Under the most favorable summer conditions, however, the high dosage of 1.5 ounces of active Systox per tree resulted in a maximum mortality of 81 per cent of citrus red mite and in an ineffective reduction of citrus bud mite populations. Apparently, this type of soil application results in inefficient control of the mites studied. These results closely resemble those obtained by Bond (1953), who found that soil applications of *Hanane* (mainly bisdimethylamino fluorophosphine oxide) for control of *Planococcus kenyae* (LePelley) on coffee were less effective than trunk treatments.

The period extending from July to October appeared to be least favorable for Systox spray treatments. However, a relatively high initial mortality of citrus red mites resulted, regardless of the month applied. When 0.5 ounce was applied during this unfavorable period, less than 100 per cent mortality resulted, as compared with complete initial mortalities from applications made November to June (Figure 1). Although the dosage of 1.5 ounces per tree produced 100 per cent initial mortalities of citrus red mite at all times, the length of the interval after treatment that toxicity persisted was shorter when applications were made in the summer than when they were made during the winter months (Figure 1). As this period of least efficiency coincides with the period when relatively high temperatures occurred on the day of treatment and throughout the month (Table 3), it appears likely that evaporation during application, and subsequent more rapid loss of surface residues, reduced the quantity of chemical entering the plant and thus adversely influenced the efficiency of applications made during this period.

When Systox was applied to the tree trunks, 7 to 20 days were required for absorption and translocation to the fruit in sufficient amounts to effect a high mortality of citrus red mite (Figure 2). Trunk applications made during November and

Table 3.—Temperature records for Escondido, California (The Church Ranch), during the period of this study.[1]

| Date of Systox Application | Temperature, °F. Maximum on Day of Treatment | Maximum for Month | Average Daily |
|---|---|---|---|
| 1952 | | | |
| May | 77 | 83.5 | 66.9 |
| June | 72 | 80.3 | 66.2 |
| July | 95 | 93.1 | 74.7 |
| August | 92 | 92.9 | 75.2 |
| September | 91 | 92.8 | 75.0 |
| October | 89 | 84.2 | 67.7 |
| November | 88 | 70.5 | 56.8 |
| December | 65 | 65.5 | 52.6 |
| 1953 | | | |
| January | — | 71.2 | 50.4 |
| February | — | 72.3 | 55.3 |
| March | 63 | 72.5 | 57.2 |
| April | 62 | 70.5 | 57.8 |

[1] Climatological Data, California Section, U. S. Department of Commerce, Weather Bureau.

December resulted in relatively ineffective kill of citrus red mite, as compared with applications made in the months of March through October (Figure 2).

The less effective results obtained from winter trunk applications than from summer trunk applications or from winter foliage sprays, suggest that trunk absorption of the toxicant or translocation through the conducting vessels of the plant may be less efficient under winter conditions. Temperature relationships did not appear to be the critical factor in this inadequate systemic activity resulting from winter trunk treatments. Average daily temperatures for November and December were 56.8° and 52.6° F., respectively, whereas the average daily temperatures for March and April, when trunk treatments were relatively effective, were 57.2° and 57.8° F., respectively (Table 3). Although average daily temperatures are only an indication of total solar energy, these comparable temperatures suggest that other factors are probably operating to reduce the movement of the toxicant from the tree trunk to the leaves and fruit during the late fall and winter months.

Wedding (1953) has pointed out that light intensity, temperature, and relative humidity of the surrounding air, as well as the amount of available soil water and the necessity of a carbohydrate reserve, may be important factors influencing translocation in plants. Several of these factors appear to be less favorable for movement of a systemic insecticide under winter conditions than under summer conditions. Further study will therefore be necessary to evaluate the importance of each of the factors responsible for variations in efficiency resulting from applications made at different seasons of the year.

Comparison of results of summer trunk applications (Figure 2) with results of summer spray applications (Figure 1) shows that trunk treatments during this period were more persistent in toxicity than sprays. Assuming that weather conditions would have the same influence on the translocated toxicant, regardless of the method of application, then under warm-weather conditions the loss of toxicant from evaporation at the time of application is greater, and the subsequent loss of residues is more rapid, when applications are made to the entire tree surface than when the concentrate material is applied to a relatively small area of the tree trunk.

Evaluation of the results against citrus bud mite indicates that Systox is relatively ineffective against this pest. Summer spray applications resulted in only slight reduction of populations of this mite, whereas fall and winter treatments failed to influence bud mite populations measurably. Inadequate control of citrus bud mite occurred from winter trunk treatments. Summer trunk applications were more effective than sprays in bud mite control. As indicated above, evaporation and residue loss may be factors resulting in the ineffectiveness of summer spray applications. Metcalf & March (1952) showed that $OMP^{32}A$ translocation was greatest in the direction of the most rapidly growing leaves. It may be that Systox likewise concentrates in the young bud tissue when distributed through the conducting vessels but remains more or less distributed when applied over the aerial parts of the trees as a spray.

SUMMARY.—Seasonal influences on efficiency of spray, trunk, and soil applications of Systox against citrus red mite, *Metatetranychus citri* (McG.), and citrus bud mite, *Aceria sheldoni* (Ewing), on lemon trees are reported. All soil applications and winter trunk treatments were

relatively inefficient against these pests. The toxicity of spray applications of Systox to citrus red mite persisted for a longer period when applied during winter months than during summer months. Summer trunk treatments resulted in a longer period of toxicity after treatment and more effective reduction of citrus bud mite populations than sprays applied concurrently. Reasons for variation in effectiveness of trunk and spray applications with the seasons are discussed.

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# Parasitization of the Salt-Marsh Caterpillar in Arizona

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Migrating armies of the salt-marsh caterpillar, *Estigmene acrea* (Drury), occasionally threaten destruction to fall plantings of vegetables in the Salt River Valley of Arizona. Large numbers develop on cotton, which is one of this caterpillar's principal host plants, but cotton growers have not been concerned by its feeding during the fall months because some benefit is derived from defoliation shortly before harvest. When their preferred food becomes scarce, the larvae migrate to lettuce and miscellaneous other crops.

The fact that these caterpillars appear in damaging numbers only in certain years indicates that they have natural enemies capable of holding down populations for several years after an outbreak. It is generally believed that this insect has become more abundant in the Salt River Valley since 1945. A satisfactory explanation of this situation requires a knowledge of the kinds of natural enemies present and of whether the relationship between the salt-marsh caterpillar and these enemies has been altered since 1945.

HISTORICAL.—Several species of tachinid (larvaevorid) parasites have been reared from salt-marsh caterpillars. Aldrich & Webber (1924) described *Zenillia reclinata*. Webber & Schaffner (1926) reported *Compsilura concinnata* (Meigen). Essig's (1926) list of tachinids includes *Zenillia* (*Exorista*) *eudryae* (Townsend), *Sturmia albifrons* Walker, *Tachina larvarum* (L.) (= *Tachina mella* Walker, *Exorista larvarum* (L.)), and *Blepharipeza adusta* Lw. (= *Rileymyia adusta* (Lw.)). Although several writers have stated that the caterpillars have been controlled by tachinid parasites, they have presented no data to verify their claim or to show the actual degree of parasitization.

Species of Hymenoptera reported as parasitizing the salt-marsh caterpillar include the ichneumonid *Enicospilus glabratus* (Say) (= *Eremotyles arctiae* Ashmead, Essig 1926), the braconid *Apanteles scitulus* Riley (= *A. rileyanus* Ashm., Sanderson 1906), and the trichogrammatid egg parasite *Trichogramma minutum* (Riley) (Girault 1916).

Many writers have reported that the salt-marsh caterpillar has been controlled with arsenicals or cryolite (e.g., Wehrle 1934, Stracener 1934). Muma *et al.* (1950) reported that BHC, applied at the rate of 0.2 and 1 pound of the gamma isomer per acre, decreased the larval populations but that 1 and 2 pounds of technical DDT per acre greatly increased the populations. The inference was that DDT eliminated the natural enemies without seriously affecting the host.

METHODS.—Studies on parasitization of the salt-marsh caterpillar were undertaken in the Salt River Valley during the fall of 1950 and continued through the fall of 1951. These studies were made to

[1] Acknowledgment is made to Laurence A. Carruth, University of Arizona, and Orin A. Hills, Entomology Research Branch, or helpful suggestions.

determine the species of natural enemies present and their ability to reduce caterpillar populations. Since cotton fields were known to support populations of these caterpillars during the fall months, observations were directed essentially toward this crop. Samples of 50 fifth-instar larvae were collected from representative cotton fields at weekly intervals, brought into the laboratory, and held in 1-gallon ice-cream cartons for pupation or completion of the life cycle of the parasite. Each carton was fitted with a funnel and a ½-pint fruit jar for recovering the adult moths and parasites. After approximately 45 days the rearing chambers containing the larvae were opened and examined. The per cent of caterpillars that did not develop into healthy pupae or moths was taken as the per cent parasitization. The results of these observations are summarized in table 1.

**Table 1.—Parasitization of salt-marsh caterpillars in 50-caterpillar samples collected from fields in the Salt River Valley of Arizona.**

| DATE | NUMBER OF SAMPLES | PER CENT PARASITIZED |
|---|---|---|
| *1950* | | |
| Sept. 25–28 | 3 | 10 |
| Oct. 3 | 1 | 11 |
| 10 | 7 | 46 |
| Nov. 10 | 1 | 15 |
| 22 | 2 | 30 |
| 29 | 2 | 50 |
| Dec. 15 | 3 | 90 |
| 20 | 1 | 56 |
| 27 | 3 | 92 |
| *1951* | | |
| Jan. 9–10 | 2 | 96 |
| Sept. 5–7 | 3 | 9 |
| 13 | 1 | 2 |
| 28 | 1 | 2 |
| Oct. 4 | 2 | 2 |
| 11 | 2 | 4 |
| 17–18 | 8 | 2 |
| 24–26 | 6 | 4 |
| 31 | 5 | 6 |
| Nov. 7 | 4 | 8 |
| 14–15 | 5 | 20 |
| 21–23 | 4 | 38 |
| 28–29 | 4 | 27 |
| Dec. 6 | 1 | 67 |

PARASITES.—Four tachinid species and one hymenopteran species were reared from larvae and pupae of salt-marsh caterpillars by these methods. The tachinid flies were determined by the Division of Insect Detection and Identification, Bureau of Entomology and Plant Quarantine, as *Exorista larvarum* (L.), *Rileymyia adusta* (Lw.), *Gymnocarcelia* sp., and *Achaetoneura archippivora* (Will.). The hymenopteran was *Ichneumon neutralis* Cress., several specimens of which were reared. *E. larvarum* and *R. adusta* were by far the most predominant species reared.

*Exorista larvarum*, a slender, greyish-black fly, varies considerably in length (7–13 mm.) depending upon the food supply. From one to four individuals were reared from a single host, but where several flies emerged from one caterpillar the individuals were smaller. *E. larvarum* lays a macrotype egg, which is white, oblong, and hemispherical and measures approximately 1 mm. in length and 0.5 mm. in width. The female fastens the egg to the skin of the caterpillar while facing the body, making contact with the tip of the abdomen, which is drawn forward between her front legs. The female usually attacks the larger larvae and has been seen attacking larvae migrating across plowed ground or trapped along barriers, as well as those feeding upon plants. Apparently the females are unable to distinguish between parasitized or unparasitized caterpillars, because from 20 to 25 eggs may be placed on an individual host caterpillar.

*Rileymyia adusta* is a large, robust fly, 7 to 14 mm. long depending on its food supply. It lays a microtype egg on plant foliage. It is usually found in association with host larvae that are feeding upon plants, never with those that are migrating across open ground or present along barriers. Dissections of females indicate that this fly is capable of laying several thousand eggs. Work of Townsend (1908) and others has shown that the microtype eggs of the species of tachinid flies that oviposit on leaves are eaten by the host.

OBSERVATIONS IN 1950.—Most all the parasites found in 1950 were *Exorista larvarum* and *Rileymyia adusta*. Parasitization in the cotton fields was lower in September than in October and November. By November parasitization had increased, but cotton was no longer attractive to the caterpillars and very few remained in cotton fields. Sampling of a later brood of caterpillars, which developed in sugar beets in November, indicated that parasitization was low initially but increased to a high degree within a month.

Salt-marsh caterpillar infestations were spotty but not severe in 1950. Nevertheless, the data indicate that the two tachinid flies were capable of inflicting a high degree of parasitization upon the salt-marsh caterpillar, although approximately 1 month was required for either species to become fully effective. Because no insecticides were applied to any fields while the 1950 observations were being made, the data show the potential of the parasites during a year of low density populations of the insect host.

OBSERVATIONS IN 1951.—Previous to a widespread outbreak in 1951 observations were begun on the brood of salt-marsh caterpillars that matured in cotton during August. By the latter part of September caterpillar populations had become extremely high in many cotton fields, and it was apparent that the September brood was distributed over the entire Salt River Valley.

The data in table 1 indicate a low parasitization of the salt-marsh caterpillar. *Exorista larvarum* and *Rileymyia adusta* were the only parasites reared from the caterpillars, and they were the same species that accounted for high parasitization in 1950. In some of the cotton fields heavy caterpillar populations persisted until the plants were completely defoliated, after which time the larvae migrated and sampling observations had to be discontinued. Parasitization in all fields was very low initially and remained low throughout October and most of November. In late November parasitization increased in those fields that still had populations available for sampling.

A cotton field in the Deer Valley area northwest of Phoenix had a moderate population of caterpillars on September 5, and 24 per cent of the fifth-instar larvae were parasitized. Shortly after the first sampling this field received an airplane application of a dust containing 15 per cent of toxaphene and 5 per cent of DDT at the rate of 30 pounds per acre. Good control of the caterpillars resulted from this treatment, and the insects did not again build up sufficient numbers for sampling until October 17. Parasitization increased in this field, reaching a peak of 82 per cent approximately 1 month later, on November 21. It is noteworthy that this was the only field of cotton studied that was not completely defoliated. The timely application of toxaphene and DDT held the caterpillars in check for more than 30 days, and thereby prevented injury to adjacent fields of lettuce. The parasitic flies were undoubtedly affected by the insecticide, but eventually recovered in sufficient numbers to bring about a high degree of parasitization and mortality of the hosts.

Since salt-marsh caterpillars had been noted to be present in fields of castor beans, one field was included in the 1951 observations. The caterpillar population was not heavy in this field, and numbers dwindled as the season progressed, until by October 18 sampling was discontinued. Parasitization was low; therefore, parasites were not a major factor contributing to the reduction of caterpillars in this crop.

The rearing data clearly indicate that the two tachinid flies that inflicted a high degree of parasitization in 1950 were not present in adequate numbers to have much effect on the caterpillar population in 1951. Sampling of the brood of caterpillars that developed in cotton during August was limited to the three samples taken on September 5 to 7. Data for these three samples indicated that the August brood was affected by a very low degree of parasitization and later produced the moths responsible for the heavy infestations of caterpillars that defoliated the cotton in October and November. The widespread outbreak that developed from a moderate August brood is further evidence that this brood was not greatly affected by parasites.

TESTS WITH INSECTICIDES AGAINST TACHINID FLIES.—To determine the effect on the tachinid parasites of some of the insecticides used to control cotton insects, four tests were run against adults of *Exorista larvarum* and *Rileymyia adusta* during the fall of 1950. These two species were reared in quantities from salt-marsh caterpillars collected in the field. Screen cages $3\frac{1}{2}$ inches in diameter and $6\frac{1}{2}$ inches high were used in these tests. Each cage was equipped with a cloth wick soaked in diluted honey to provide food for the flies. All insecticides were tested as dusts prepared in the laboratory. The cages with the food in place were dusted in a settling chamber just before the flies were introduced. Applications were made with a microduster at the rate of 0.25 gram per

square foot, which is equivalent to approximately 30 pounds per acre.

Table 2 shows that all the insecticides tested gave high kills of these flies. Ten-per cent DDT gave a significantly higher kill than 15-per cent toxaphene 4 hours after treatment, but there were no differences after 6 and 24 hours. Five-per cent DDT and 15-per cent toxaphene had the same effect 4, 6, and 24 hours after treatment. In test No. 3 a small quantity of BHC (12 per cent gamma) was spilled just before the experiment was set up. The air in the laboratory was undoubtedly contaminated, for all the flies were killed together with those in the rearing cabinet This demonstrated the highly toxic effect of BHC on the adult parasites. In test No. 4 aldrin gave a significantly lower mortality than dieldrin and parathion after 4 and 6 hours, but all dusts were equally effective after 24 hours.

**Table 2.—Mortality of adult tachinid parasites placed in cages dusted with insecticides, 1951.**

| Insecticide (Figures in Per Cent) | Per Cent Mortality After— | | |
|---|---|---|---|
| | 4 Hours | 6 Hours | 24 Hours |
| *Test No. 1, 5 replicates of 6 flies each* | | | |
| Toxaphene 15 | 40 | 70 | 93 |
| DDT 10 | 97 | 97 | 100 |
| Untreated check | 10 | 17 | 43 |
| L.S.D. (0.05%) | 28 | 33 | 17 |
| *Test No. 2, 3 replicates of 6 flies each* | | | |
| Toxaphene 15 | 38 | 60 | 88 |
| DDT 5 | 43 | 43 | 100 |
| Untreated check | 0 | 0 | 17 |
| L.S.D. (0.05%) | [1] | 37 | 25 |
| *Test No. 3, 3 replicates of 5 flies each* | | | |
| BHC, gamma 2 | 100 | 100 | 100 |
| Parathion 2 | 80 | 86 | 100 |
| Dieldrin 2 | 72 | 92 | 100 |
| Aldrin 2 | 32 | 80 | 100 |
| Untreated check | 12 | 54 | 100 |
| L.S.D. (0.05%) | 18 | [2] | [2] |
| *Test No. 4, 3 replicates of 5 flies each* | | | |
| Aldrin 2 | 12 | 52 | 100 |
| Dieldrin 2 | 66 | 86 | 100 |
| Parathion 2 | 80 | 86 | 100 |
| Untreated check | 0 | 0 | 0 |
| L.S.D. (0.05%) | 26 | 28 | [2] |

[1] Not significant by the F test.
[2] Data not analyzed statistically.

TESTS WITH INSECTICIDES AGAINST PARASITIZED SALT-MARSH CATERPILLARS.—A laboratory test with toxaphene and DDT was conducted against parasitized fifth-instar salt-marsh caterpillars collected from sugar beets on January 11, 1951. Parasitization of the larvae in this field had previously been determined by rearing, to be 100 per cent. *Exorista larvarum* and *Rileymyia adusta* accounted for this high parasitization, the latter being the predominant species at a ratio of 3:1. To further assure that only parasitized larvae were used in this test, only those that had one or more macrotype tachinid eggs attached to the skin were used.

This test consisted of four treatments each replicated four times. Each replicate consisted of 10 caterpillars confined in wide-mouth quart Mason jars. The bottoms of the jars were covered with 2 inches of peat moss, and the tops were equipped with screen lids. These caterpillars were fed lettuce leaves that had been sprayed with toxaphene, DDT, or a mixture of both insecticides, 1 pound of each toxicant to 20 gallons of water. Leaves were sprayed until thoroughly covered and then shaken to remove excess spray. Untreated leaves were fed to a check series of caterpillars. Adequate amounts of freshly treated leaves were made available to these larvae during a 3-day period, after which untreated fresh leaves were added as needed until all activity within the jars had ceased.

Table 3 shows that the parasitized caterpillars exposed to the toxaphene and toxaphene-DDT treatments did very little feeding, while those exposed to the DDT treatment and the untreated check consumed more than three leaves each. Significantly fewer tachinid flies emerged from both the toxaphene and toxaphene-DDT treatments than from the DDT treatment, although all the insecticides reduced the number of tachinid flies emerging significantly below the numbers emerging from the untreated check.

DISCUSSION.—There appears to be a relationship between the increased im-

**Table 3.—Effect of insecticides on parasites within the body of the salt-marsh caterpillar.**

| Treatment[1] | Mean Number of Leaves Consumed | Mean Number of Emerging Insects | | |
|---|---|---|---|---|
| | | Moths | Parasites | |
| | | | *E. larvarum* | *R. adusta* |
| Toxaphene | 0.4 | 0 | 1.0 | 1.0 |
| Toxaphene and DDT | 0.1 | 0 | 1.8 | 2.5 |
| DDT | 3.3 | 0.8 | 4.0 | 8.2 |
| Untreated check | 3.8 | 0 | 5.2 | 15.5 |
| L.S.D. (0.05%) | — | — | 0.7 | 2.7 |

[1] Four replicates.

Table 4.—Millions of pounds of insecticides applied to cotton in Arizona, 1945–1951.[1]

| INSECTICIDE (Figures in Per Cent) | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 |
|---|---|---|---|---|---|---|---|
| Paris green 7.5, 15 | 2.3 | — | — | — | — | — | — |
| DDT, 5, 10 | — | 5.0 | 9.0 | 10.2 | 12.6 | 12.0 | 22.5 |
| DDT 5 plus— | | | | | | | |
| BHC, gamma 2 | — | — | — | 1.2 | 3.6 | 6.0 | 2.1 |
| Toxaphene 10, 15 | — | — | — | 0.6 | 1.8 | 2.0 | 3.9 |
| Other materials such as aldrin 2 or dieldrin 2 | — | — | — | — | — | — | 1.5 |
| All insecticides | 2.3 | 5.0 | 9.0 | 12.0 | 18.0 | 20.0 | 30.0 |

[1] Furnished by J. N. Roney, Extension entomologist, University of Arizona.

portance of the salt-marsh caterpillar, the increased cotton acreage, and the increased use of insecticides (almost entirely chlorinated hydrocarbons) by Arizona cotton growers from 1945 to 1951. During this period cotton acreage increased from 155,502 acres to 539,247 acres. Insecticides have seldom been applied for control of the salt-marsh caterpillar on cotton, since this insect usually occurs in abundance only during the fall months when frosts are expected and defoliation is desired. If they have caused any reduction of these caterpillars in cotton, it has been coincidental with the chemical control of other insects considered more detrimental to this crop.

As shown in table 4, the quantity of insecticides applied to cotton in Arizona increased 13-fold from 1945 to 1951. In 1945 paris green was practically the only insecticide applied. Since 1946 almost all the insecticides have contained DDT.

Arsenicals have been recommended for the control of the salt-marsh caterpillar. DDT, on the other hand, has been shown to be ineffective against this insect (Table 3, Muma *et al.* 1950). DDT and other chlorinated hydrocarbon insecticides used on cotton have been shown to be highly toxic to the two tachinid flies that are effective parasites of this caterpillar (Table 1). The increased use of DDT for controlling other insects affecting cotton undoubtedly has adversely affected the natural enemies of the salt-marsh caterpillar. Thus an environment created by the use of this insecticide on the primary host plant has produced conditions favorable for high populations of the salt-marsh caterpillar.

SUMMARY.—The salt-marsh caterpillar, *Estigmene acrea* (Drury), damages fall vegetable plantings in Arizona. The insect has become more abundant since 1945. To account for this situation, a study was made of the natural enemies of this caterpillar.

Two species of tachinid flies, *Exorista larvarum* (L.) and *Rileymyia adusta* (Lw.), caused a high degree of parasitization of fifth-instar caterpillars in the field. Laboratory tests indicated that adults of both species were readily killed by insecticides commonly applied to cotton in Arizona. Limited experiments indicated that DDT killed the tachinid parasites within the caterpillars, thus permitting the latter to live and complete their normal development. This evidence strongly suggests that the widespread use of DDT on cotton has reduced the parasite population. However, this insecticide has very little direct effect upon the caterpillar. The relationship between the insect host and its natural enemies appears to have thus been altered by external factors to favor the development of high populations of the host.

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# Control of Greenhouse Whitefly and Other Insects on Beans in Hawaii[1]

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The greenhouse whitefly, *Trialeurodes vaporariorum* (Westw.), the bean leafhopper, *Empoasca solana* De Long, and the bean pod borer, *Maruca testulalis* (Geyer) are among the most damaging insect pests of green beans in Hawaii. During 1952 and 1953, several experiments were conducted on the islands of Hawaii and Oahu to determine the efficacy of a number of organic insecticides in controlling these insects. In all of the experiments the Hawaiian Wonder variety of pole bean was used.

WHITEFLY CONTROL STUDIES.—Four small-plot experiments were carried out against the greenhouse whitefly. In experiment 1, each plot consisted of three rows 25 feet long. The rows were spaced 4 feet apart and there was a 5-foot unplanted space between the plots along the rows. In the other three experiments, each plot was a single row 10 feet long. The rows were spaced 8 feet apart and there was a 5-foot unplanted space between the plots along the rows. Each plot contained one hill per foot of row with two plants in each hill.

The infestation data were based on counts of the nymph population. Starting with the third plant in the row a total of either 10 or 20 terminal leaflets of approximately the same age were taken at random from each plot. Since it was impractical to count all of the nymphs on each leaf, a subsampling procedure was used. Four circular impressions were made at random on each leaf using a No. 10 cork borer. The total area per leaf encompassed by these impressions was 1018 $mm^2$. This area on each leaf was examined and the number of nymphs tallied. The insecticides were applied by knapsack sprayer.

*Experiment 1* (*Kona, Hawaii*).—The experimental field consisted of 48 plots and was planted on April 25, 1952. The whitefly infestation was late in becoming established in the experimental area. Although farmers in the Kona area were faced with a whitefly problem by June 23, it wasn't until July 17 that the experimental plots became sufficiently infested to warrant spraying.

Fifteen treatments were applied and were replicated three times. The following insecticides were used: as wettable powders—parathion, DDT, methoxychlor, chlordane, toxaphene, and dieldrin; as emulsifiable concentrates—toxaphene, and aldrin. The concentrations at which these insecticides were applied on June 23, July 30, and August 6, and the results of the treatments are given in table 1.

Parathion at 1 pound of the 25 per cent wettable powder per 100 gallons gave the best control. Although the prespray infestation (July 17) in the parathion plots was high, the infestation declined through August 12, but began to build up again by August 21.

Parathion, DDT, methoxychlor, dieldrin, and chlordane at 4 pounds of formulation per 100 gallons, toxaphene suspension at 5 pounds of formulation per 100 gallons, and aldrin emulsifiable concentrate at 1:400 significantly reduced the nymph population over that found in the

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untreated plots on August 12. However, 15 days after the last spray application, the infestation had appreciably increased in all of the plots except those treated with 1 pound of 25 per cent parathion per 100 gallons.

*Experiment 2* (*Poamcho, Oahu*).—The experimental area consisted of 60 plots which were planted on December 16, 1952. Nine treatments were applied and were replicated six times. The following wettable powder insecticides were included in this experiment: toxaphene, heptachlor, EPN, and a combination of DDT plus sulfur. The concentrations at which these materials were applied on March 5, 17, and 23, and the results of the treatments are given in table 2. On March 17, the untreated check plots were sprayed with Aramite at the rate of 2 pounds of the 15 per cent wettable powder per 100 gallons to reduce an infestation of *Tetranychus bimaculatus* Harvey.

Heptachlor gave the poorest control while the use of EPN resulted in excellent protection. DDT-sulfur-treated plants had tough, thickened leaves. On April 20, 1 month after treatment, the condition of the plants in the field was observed. The untreated plots had great numbers of red spider mites, leafhoppers, and whiteflies. EPN-treated plants were in the best condition and had very low infestations of insects or mites. Heptachlor-treated plants on the other hand were very seriously damaged by mites.

**Table 1.—Insecticide tests against the greenhouse whitefly on pole beans (Experiment 1).**

| Insecticide[1] | Pounds per 100 Gals. | Average Number[2] of Nymphs per Leaf Sample (1018 mm.²) | | |
|---|---|---|---|---|
| | | Pre-spray July 17 | August 12 | August 21 |
| Parathion 25% w.p. | 1 | 481 | 27 | 102 |
| | 0.5 | 283 | 65 | 1276 |
| Toxaphene 71% emul. | 1:800 | 265 | 260 | 1178 |
| | 1:1600 | 420 | 416 | 1590 |
| Toxaphene 40% w.p. | 5 | 455 | 31 | 827 |
| | 2.5 | 563 | 9 | 2396 |
| DDT 50% w.p. | 4 | 324 | 138 | 748 |
| | 2 | 713 | 173 | 1808 |
| Methoxychlor 50% w.p. | 4 | 202 | 81 | 1378 |
| Chlordane 50% w.p. | 4 | 217 | 110 | 1331 |
| | 2 | 302 | 240 | 2131 |
| Aldrin 25% emul. | 1:400 | 208 | 133 | 1038 |
| | 1:800 | 193 | 348 | 1766 |
| Dieldrin 25% w.p. | 4 | 443 | 179 | 1563 |
| | 2 | 218 | 409 | 1194 |
| Untreated | — | 90 | 486 | 2361 |
| L.S.D. (19:1): | | | 281 | |

[1] Dates of application: July 23, July 30, and August 6, 1952.
[2] To nearest whole number.

**Table 2.—Insecticide tests against the greenhouse whitefly (Experiment 2).**

| Insecticide[1] | Pounds per 100 Gals. | Average Number of Nymphs per Leaf Sample (1018 mm.²) | |
|---|---|---|---|
| | | March 30 | April 13 |
| Toxaphene 40% w.p. | 2.5 | 11.2 | 15.6 |
| | 1.25 | 19.8 | 38.8 |
| Heptachlor 25% w.p. | 8 | 14.6 | 11.0 |
| | 4 | 63.6 | 145.8 |
| | 2 | 34.0 | 37.9 |
| DDT 50% w.p.+S | 4+5 | 23.2 | 9.6[2] |
| | 2+5 | 17.7 | 7.5[2] |
| EPN 27% w.p. | 3.7 | 4.4 | 0.5[3] |
| | 1.9 | 9.3 | 4.8[3] |
| Untreated | — | 31.9 | 43.1 |

[1] Dates of application: March 5, 17, and 23, 1953.
[2] Significant at 5 per cent level.
[3] Significant at 1 per cent level.

*Experiment 3* (*Kona, Hawaii*).—The experimental field consisted of 80 plots and was planted on February 20, 1953. By March 18, the whitefly infestation had become great enough to warrant spraying. Nine treatments were applied and were replicated eight times. The following wettable powder insecticides were used in this experiment: DDT plus sulfur, parathion, toxaphene, methoxychlor plus sulfur, lindane, and chlordane. The concentrations at which these materials were applied on March 31, April 7, and April 14, and the results of the treatments are given in table 3.

Leaf samples were collected prior to spraying the plots and collections were continued through June 2. The leaves were picked at a height of 3 to 4 feet from the ground.

Although the infestation in the untreated plots continued to increase throughout the period of observation, the whitefly infestations in the treated plots had decreased tremendously by April 21. On May 12, the population was still fairly low in the parathion, toxaphene, methoxychlor, and chlordane plots but was increasing. Since the plants were fairly young when the initial three spray applications were made, leaf samples were also taken on May 12 from the tops of the plant, an area which had received no spray. This was done to compare the whitefly population in these two regions of growth. The top growth had a higher population of whiteflies than did the

**Table 3.—Insecticide tests against the greenhouse whitefly on pole beans (Experiment 3).**

| Insecticide[1] | Pounds per 100 Gals. | Average Number[2] of Nymphs per Leaf Sample (1018 mm.[2]) | | | | | | Pounds[2] per 160 Plants (4/24–6/12) |
|---|---|---|---|---|---|---|---|---|
| | | Pre-spray March 31 | April 21 | May 12 | May 12[3] | May 26 | May 26[3] | |
| DDT 50%+S | 4+5 | 658 | 11 | 159 | 396 | 404 | 510 | 188 |
| DDT 50%+S | 2+5 | 642 | 15 | 217 | 567 | 436 | 518 | 176 |
| Parathion 25% | 1 | 880 | 0.1[4] | 95[4] | 351 | 16[4] | 24[4] | 240 |
| Parathion 25% | .5 | 609 | 0.3[4] | 74[4] | 390 | 135 | 73[4] | 245 |
| Toxaphene 40% | 5 | 773 | 0.8[4] | 16[4] | 299 | 188 | 326 | 211 |
| Toxaphene 40% | 2.5 | 784 | 7 | 63[4] | 673 | 361 | 332 | 202 |
| Methoxychlor 50%+S | 4+5 | 798 | 2 | 119 | 374 | 477 | 526 | 190 |
| Lindane 25% | 1 | 541 | 8 | 201 | 508 | 494 | 406 | 211 |
| Chlordane 50% | 4 | 580 | 10 | 102 | 565 | 243 | 314 | 224 |
| Untreated | — | 642 | 904 | 1195 | 1776 | 1149 | 1268 | 73 |
| L.S.D. (19:1) | | | | | | | | 24 |
| (99:1) | | | | | | | | 32 |

[1] Applied as wettable powders March 31, April 7, April 14, May 18, 1953.
[2] To nearest whole number where values are more than 1.
[3] Leaf samples taken from very top of plants. All other leaf samples taken 3 to 4 feet from ground.
[4] Best treatments. Significantly better than other treatments at 5 per cent level.

general region which had received sprays. Therefore, the plants were sprayed again on May 18. This second series of sprays resulted in a further decrease in infestation only in the parathion plots.

Yield data were taken throughout the course of this experiment. The beans were harvested three times per week from April 24 to June 12. Table 3 summarizes these data. All of the plots which received insecticidal treatment had significantly greater yields than the untreated plots. In comparing the yield between treatments the following order occurred: parathion > chlordane = lindane > toxaphene > DDT = methoxychlor. It was noted that the DDT-sprayed leaves were thicker and coarser than the leaves from plants sprayed with the other insecticides. This apparent phytotoxicity may have contributed to the low yield of the DDT-sprayed plots.

The bean leaves in the untreated plots were covered with sooty mold due to the high population of whiteflies present.

*Experiment 4 (Kona, Hawaii).*—The experimental field consisted of 72 plots and was planted on June 19, 1953. By July 8, although the plants were less than 1 foot tall, they were so heavily infested with whitefly eggs that control measures were initiated. Nine treatments were applied and were replicated four times. Each of these treatments was made under two schedules, A and B. The insecticides in schedule A were applied three times at weekly intervals on July 9, 15, and 22. The insecticides in schedule B were applied three times at biweekly intervals on July 9, 22, and August 5. The following wettable powder insecticides were used in this study: parathion, malathion, CS-708 and EPN. The concentrations at which these insecticides were applied and the results of the treatments are given in table 4.

The infestation in the untreated plots although it fluctuated remained high until August 26 when it dropped sharply. However, by September 9, the infestation had risen again. There was a faster drop in infestation in the treated plots of schedule A than in those of schedule B but by July 29 all of the insecticide-sprayed plots had low nymph populations. The September 9 count showed a sharp increase in the infestation in the treated plots. In general, the protection afforded by schedule A was greater than that of schedule B. By September 9, EPN, parathion, and malathion gave good protection when applied under schedule A, while only EPN was effective under schedule B.

The beans were harvested three times per week between August 12 and September 14. The yield data are summarized in table 4. All treated plots yielded higher than the untreated plots except the plots sprayed with malathion at 4 pounds per

**Table 4.—Insecticide tests against the greenhouse whitefly on pole beans (Experiment 4).**

| INSECTICIDE (WETTABLE POWDERS) | POUNDS PER 100 GALS. | PRE-SPRAY JULY 8[2] EGGS | AVERAGE NUMBER OF NYMPHS PER LEAF SAMPLE (1018 mm.²) | | | | POUNDS[2] PER 80 PLANTS (8/12–9/14) |
|---|---|---|---|---|---|---|---|
| | | | July 22 | July 29[1] | Aug. 12 | Sept. 9[2] | |
| *Schedule A* (treatments applied July 9, 15, and 22) | | | | | | | |
| Parathion 25% | 0.5 | 1486 | 0.6 | 0 | 1.2 | 170 | 96 |
| Malathion 25% | 4 | 1455 | 15.9 | 0.2 | 0.5 | 42 | 85 |
| | 2 | 1629 | 58.0 | 0.6 | 1.3 | 155 | 85 |
| | 1 | 1594 | 41.5 | 4.1 | 1.7 | 67 | 87 |
| CS-708 25% | 4 | 1420 | 11.8 | 6.9 | 10.2 | 271 | 111 |
| | 2 | 1834 | 54.0 | 8.0 | 33.8 | 149 | 83 |
| EPN 27% | 4 | 1589 | 0.2 | 0 | 0.2 | 70 | 111 |
| | 2 | 1465 | 0.2 | 0 | 0.4 | 50 | 102 |
| Untreated | — | 1641 | 399.1 | 305.0 | 131.6 | 390 | 62 |
| L.S.D. at 5 per cent level: | | | 82.6 | — | 68.4 | 185 | 19 |
| *Schedule B* (treatments applied July 9, 22, and Aug. 5) | | | | | | | |
| Parathion 25% | 0.5 | 1481 | 49.0 | 6.8 | 0.1 | 105 | 103 |
| Malathion 25% | 4 | 1420 | 135.6 | 20.9 | 37.2 | 133 | 75 |
| | 2 | 1229 | 21.4 | 4.7 | 21.4 | 181 | 92 |
| | 1 | 1322 | 102.7 | 2.7 | 35.2 | 195 | 81 |
| CS-708 25% | 4 | 988 | 83.0 | 0.9 | 20.7 | 446 | 88 |
| | 2 | 1483 | 113.6 | 10.0 | 218.3 | 572 | 90 |
| EPN 27% | 4 | 1418 | 23.3 | 0 | 0 | 18 | 95 |
| | 2 | 1207 | 1.7 | 0.3 | 0.1 | 29 | 96 |
| Untreated | — | 1204 | 430.4 | 306.4 | 335.9 | 250 | 61 |
| L.S.D. at 5 per cent level: | | | 82.6 | — | 68.4 | 185 | 19 |

[1] No significant difference between treatments. All treatments resulted in significantly lower infestations than in untreated checks.
[2] To nearest whole number.

**Table 5.—Insecticide tests against *Maruca testulalis* on pole beans. 1953.**

| INSECTICIDE (WETTABLE POWDERS) | POUNDS PER 100 GALS. | PER CENT PODS INFESTED | | | | |
|---|---|---|---|---|---|---|
| | | Before Treatment | Days After Treatment | | | |
| | | | 2 | 4 | 7 | 9 |
| *Experiment 1* (1 application, May 18) | | | | | | |
| DDT 50%+S | 4+5 | 27 | 24 | — | 0 | — |
| | 2+5 | 26 | 10 | — | 0 | — |
| Parathion 25% | 1 | 34 | 14 | — | 0 | — |
| | .5 | 29 | 18 | — | 0 | — |
| Toxaphene 40% | 5 | 29 | 18 | — | 0 | — |
| | 2.5 | 39 | 17 | — | 0 | — |
| Methoxychlor 50% | 4 | 27 | 26 | — | 6 | — |
| Lindane 25% | 1 | 30 | 12 | — | 0 | — |
| Chlordane 50% | 4 | 41 | 24 | — | 4 | — |
| Untreated | — | 21 | 58 | — | 10 | — |
| *Experiment 2* (2 applications, April 21 and 27) | | | | | | |
| DDT 50%+S | 4+5 | 28 | — | 2 | 2 | 2 |
| | 2+5 | 26 | — | 2 | 2 | 2 |
| Methoxychlor 50% | 4 | 23 | — | 4 | 2 | 3 |
| | 2 | 21 | — | 6 | 2 | 4 |
| CS-708 | 8 | 24 | — | 2 | 2 | 1 |
| | 4 | 28 | — | 2 | 2 | 1 |
| Cryolite 90% | 9 | 25 | — | 4 | 2 | 3 |
| Malathion 25% | 2.5 | 24 | — | 3 | 2 | 5 |
| | 1.5 | 30 | — | 4 | 2 | 3 |
| Untreated | — | 22 | — | 15 | 11 | 13 |

**Table 6.—Insecticide tests against the bean leafhopper on pole beans.**

| Insecticide | Pounds per 100 Gals. | Average Number of Nymphs per Leaf: Before Treatment | Weeks After Treatment: 1 | 2 |
|---|---|---|---|---|
| *Experiment 1* (applications, August 15 and 21, 1952) 4 replications | | | | |
| Aldrin 23% emuls. | 1–400 | 9.4 | 39.1 | 15.9 |
| | 1–800 | 17.8 | 40.3 | 16.2 |
| Dieldrin 25% w.p. | 4 | 12.7 | 13.5 | 14.2 |
| | 2 | 9.7 | 22.3 | 11.0 |
| Chlordane 50% w.p. | 4 | 10.6 | 23.5 | 19.6 |
| | 2 | 16.1 | 34.1 | 14.1 |
| CS-708, 25% w.p. | 8 | 12.0 | 3.1 | 0.9 |
| Endrin 10% w.p. | 10 | 14.3 | 4.7 | 1.3 |
| Isodrin 10% w.p. | 10 | 9.8 | 6.1 | 1.0 |
| Untreated | — | 13.8 | 39.6 | 19.6 |
| L.S.D. (19:1) | | | 15.9 | 7.9 |
| *Experiment 2* (applied, Jan. 29, 1953) 9 replications | | | | |
| Parathion 25% w.p. | 1 | 2.7 | 0.8 | — |
| | 0.5 | 4.5 | 2.1 | — |
| Metacide 31% emuls. | 1–400 | 2.9 | 1.2 | — |
| | 1–800 | 3.0 | 3.3 | — |
| NPD[1] 25% w.p. | 2 | 3.4 | 5.1 | — |
| | 1 | 3.5 | 5.4 | — |
| Systox emuls., 2 lbs./gal. | 1–800 | 3.4 | 2.5 | — |
| | 1–1600 | 2.6 | 3.4 | — |
| Untreated | — | 3.2 | 8.3 | — |
| L.S.D. (19:1) | | | 1.3 | |
| *Experiment 3* (applications, March 5 and 17, 1953) 6 replications | | | | |
| Toxaphene 40% w.p. | 2.5 | — | 0.3 | 0.1 |
| | 1.25 | — | 0.2 | 0.2 |
| Heptachlor 25% w.p. | 8 | — | 0.2 | 0.1 |
| | 4 | — | 0.6 | 0.3 |
| | 2 | — | 0.8 | 0.2 |
| DDT 50% w.p.+S | 4+5 | — | 0.1 | 0.1 |
| | 2+5 | — | 0.1 | 0.1 |
| EPN 27% w.p. | 3.7 | — | 0.1 | 0 |
| | 1.9 | — | 0 | 0.1 |
| Untreated | — | — | 2.0 | 1.0 |
| L.S.D. (19:1) | | | 0.5 | 0.3 |
| *Experiment 4* (applications, April 21 and 27, 1953) 5 replications | | | | |
| Methoxychlor 50% w.p. | 4 | — | 0.1 | — |
| | 2 | — | 0.3 | — |
| CS-708 25% w.p. | 4 | — | 0.3 | — |
| | 2 | — | 0.1 | — |
| Cryolite 90% w.p. | 8.9 | — | 2.8 | — |
| DDT 50% w.p.+S | 4+5 | — | 0.6 | — |
| | 2+5 | — | 0.2 | — |
| Malathion 25% w.p. | 2.5 | — | 0.6 | — |
| | 1.5 | — | 0.5 | — |
| Untreated | — | — | 1.4 | — |

[1] Tetra-n-propyl dithionopyrophosphate.

100 gallons in schedule B. Despite the fact that CS-708 gave poorer control of the whitefly than some of the other insecticides, the yields in the CS-708-treated plots were high. It was noted throughout these experiments that the first instar nymphs were much more readily killed by the insecticides than the older nymphs.

BEAN POD BORER CONTROL STUDIES. The bean pod borer can be a most destructive pest of grean beans. In one large planting of beans which had not been sprayed, the infestation by this insect rose to 35 per cent of the harvested beans. Two experiments were conducted to control this insect. Table 5 summarizes the results of these experiments.

*Experiment 1* (*Kona, Hawaii*).—In connection with whitefly experiment 3, it was found that beans harvested during the middle of May, 1953 were heavily infested with bean pod borer. The field was sprayed on May 18 and the infestation from harvested beans was subsequently measured. By May 22, the infestation had practically disappeared in the treated plots and had decreased considerably in the untreated plots. This latter observation can possibly be explained by the fact that untreated plants had been so heavily damaged by the whiteflies that the yield had been substantially decreased and there were very few beans from these plants at harvest time. In addition, this being a small-plot experiment the adult moths may have been eliminated from the treated plots where they were hiding during the day.

*Experiment 2* (*Waimanalo, Oahu*).—The experimental area consisted of 50 plots, each of which consisted of one row 10 feet long. Between each row was a barrier row and there was a 5-foot unplanted space between the plots along the rows. The field was planted on February 9, 1953. By April 20, approximately 25 per cent of the harvested beans were infested with the pod borer. Methoxychlor, CS-708, cryolite, DDT plus sulfur, and malathion were applied by knapsack sprayer to the plants on April 21 and 27. The applications were light with emphasis on bean pod coverage rather than complete leaf coverage. All of the insecticidal treatments successfully reduced the infestation.

LEAFHOPPER CONTROL STUDIES. Four small-plot experiments were conducted against the bean leafhopper. The experimental plot layout was described under the whitefly control studies.

The infestation data were based on counts of the nymph population. Starting with the third plant in the plot a total of 10 or 20 terminal leaflets were taken at random from each plot and placed in a bag containing chloroform. The bags were tightly sealed and taken to the laboratory where the number of nymphs present was determined.

The insecticides were applied by knapsack sprayer in all but experiment 2 where a power sprayer was used. The insecticides

used and the results obtained are summarized in table 6.

In experiment 1, CS-708 at 8 pounds of the 25 per cent wettable powder and isodrin and endrin at 10 pounds of the 10 per cent wettable powder per 100 gallons gave excellent control of the leafhopper 2 weeks after treatment. Chlordane at 4 pounds of the 50 per cent wettable powder per 100 gallons and aldrin at a dilution of 1–400 of the 23 per cent emulsifiable concentrate gave no control.

In experiment 2, the effect of several phosphate insecticides on the leafhopper was studied. Although all of the insecticide treatments significantly reduced the leafhopper infestation when compared with the untreated plots 1 week after treatment, NPD gave significantly poorer control than the other materials.

In experiment 3, the effect of toxaphene, heptachlor, DDT and EPN on the leafhopper was studied. All of the insecticide treatments significantly reduced the infestation both 1 week and 2 weeks after treatment.

In experiment 4, which was more fully described in connection with bean pod borer experiment 2, cryolite gave no control of the leafhopper while CS-708 at 2 pounds of the 25 per cent wettable powder, methoxychlor at 4 pounds of the 50 per cent wettable powder, and DDT at 2 pounds of the 50 per cent wettable powder per 100 gallons gave good control and malathion at 2.5 pounds of the 25 per cent wettable powder per 100 gallons gave only fair control. Spray coverage of the plants was not thorough since emphasis was placed on spraying the pods to control the borer.

SUMMARY.—Several small-plot experiments were conducted in 1952 and 1953 to determine the effectiveness of insecticides applied as sprays in controlling the greenhouse whitefly, *Trialeurodes vaporariorum* (Westw.), the bean leafhopper, *Empoasca solana* De Long, and the bean pod borer, *Maruca testulalis* (Geyer).

In three experiments in which three sprays were applied at weekly intervals to control the whitefly, 0.032 per cent parathion and 0.063 per cent EPN gave excellent control while the following materials gave good control: 0.016 per cent parathion, 0.25 per cent DDT, methoxychlor, and chlordane, 0.125 per cent toxaphene and dieldrin, and 0.063 per cent aldrin. In a fourth experiment, a comparison was made of the effectiveness of three sprays of parathion, malathion, CS-708 and EPN applied at weekly and biweekly intervals to control this insect. EPN was equally effective under either application schedule. Parathion, malathion, and CS-708 were more effective when they were applied at weekly intervals.

All of the materials tested were effective in controlling the bean pod borer and the bean leafhopper.

## BOOK REVIEW

THE STATISTICS OF BIOASSAY, WITH SPECIAL REFERENCE TO THE VITAMINS, by C. I. Bliss. Academic Press, Inc., 125 East 23rd Street, New York 10, New York. 1952. 9×6 inches, 183 pages, 67 tables, 12 figures. $3.50.

The text of this book was prepared primarily for workers in the field of vitamin research. However, the techniques presented should be very useful for the biological assay of any chemical in which animals, in the broad sense of the word, are used. Not all of the features of the techniques may apply directly to experiments with insects but the discussions of the basis for dosage-response lines and the statements of the principles involved are presented thoroughly in a fresh and interesting manner.

The book is written as a working manual for biologists and attempts to indicate the purpose of each statistic and provide working directions for its calculation. A knowledge of algebra is the only prerequisite in mathematics. This book will be useful to both the beginner and those with experience in the use of regression and dosage-mortality techniques.

A review of the general principles of biological assay is used to introduce the reader to the development of the statistical techniques. The presentation of each additional concept is accompanied with an example problem. The presentation of statistical techniques covers the field from the computation of a dosage-response curve from individual observations to methods of quality control in repeated assays and collaborative experiments. A glossary of symbols, an index to equations and a subject index are given.

The exposition of such basic concepts as N-2, the least sum of squares of deviations from the line, the standard error of the line and others is particularly good. The manner in which the application of analysis of variance to the regression components is presented, discussed and illustrated will surely provide better comprehension of this technique and extend its use. Many suggestions for saving calculation time are offered.

LOUIS A. RIEHL

# SCIENTIFIC NOTES

## Reaction of Sorghum Varieties to the Chinch Bug

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*Stillwater, Oklahoma*

Since the reaction of sorghums to the chinch bug, *Blissus leucopterus* (Say), was reported by Snelling *et al.* (1937), several new varieties have been distributed to farmers in Texas, Oklahoma, and Kansas. A study of the reaction of this insect to some of these new varieties in comparison with that of some of the older standard ones is presented herein.

Chinch bug sorghum nurseries at Lawton and Stillwater, Oklahoma, were seeded in late May or early June. Each variety was seeded in single 50-foot rows replicated four times. Three weeks after seeding the nurseries were thinned to leave 6 inches between plants, or approximately 100 plants per row, and the number of plants in each row was recorded. When chinch bugs were abundant, live plant counts were made every 3 weeks during the season.

Most of the varieties tested had shown some adaptation to Oklahoma conditions, but some advanced hybrids and varieties used in the sorghum-breeding project were included.

In 1946 and 1949 the chinch bug infestation was rather severe at both Stillwater and Lawton. In both years, migration of the bugs into the nurseries occurred by flight and uniform infestations appeared

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**Table 1.—Percentage of sorghum plants killed by chinch bugs, Oklahoma, 1946 and 1949.**

| Variety | Record Number | 1946 | | 1949 | | Average | | |
|---|---|---|---|---|---|---|---|---|
| | | Stillwater | Lawton | Stillwater | Lawton | Stillwater | Lawton | Average |
| Grain sorghums: | | | | | | | | |
| Bonita | — | 60.5 | 43.8 | 49.7 | 76.3 | 55.1 | 60.1 | 57.6 |
| Caprock | — | 56.9 | — | 24.9 | 61.3 | 40.9 | 61.3 | 51.1 |
| Club-Day×338 | — | 31.3 | — | 24.1 | 52.4 | 27.7 | 52.4 | 40.1 |
| Club kafir | C.I. 901 | 14.0 | — | — | — | 14.0 | — | — |
| Club×Day | 38-16 | 29.4 | 24.9 | 33.8 | 36.5 | 31.6 | 30.7 | 31.2 |
| Darso | Okla. No. 1 | 17.5 | 9.1 | 8.8 | 9.6 | 13.2 | 9.4 | 11.3 |
| Darso (Sel.) | Sel. from Okla. No. 1 | 18.2 | — | — | — | 18.2 | — | — |
| Dwarf Kafir | 44-14 | 52.7 | 35.3 | 25.6 | 31.0 | 39.2 | 33.2 | 36.2 |
| Early milo 480× Milo 332 $F_4$ | 51-5 | — | — | 11.0 | 21.7 | 11.0 | 21.7 | 16.4 |
| Hegari | C.I. 750 | 59.0 | 45.9 | 18.1 | 79.4 | 38.6 | 62.7 | 50.7 |
| Hydro | C.I. 1023 | 30.2 | — | — | — | 30.2 | — | — |
| Kaferita | C.I. 811 | 12.0 | 7.5 | 3.5 | 2.4 | 7.8 | 5.0 | 6.4 |
| Kaferita | C.I. 812 | 25.1 | 25.4 | — | — | 25.1 | 25.4 | 25.3 |
| Martin | SA 5330 | 34.7 | 18.1 | 19.1 | 25.8 | 26.9 | 22.0 | 24.5 |
| Midland | H.C. 617 | 67.4 | — | 20.4 | 73.7 | 43.9 | 73.7 | 58.8 |
| Milo 51×C.I. 811 | 51-2 | — | — | 9.7 | 19.5 | 9.7 | 19.5 | 14.6 |
| Plainsman | — | 68.3 | — | 20.8 | 73.0 | 44.6 | 73.0 | 58.8 |
| Redlan | — | 20.4 | 7.7 | 5.7 | 13.7 | 13.2 | 10.7 | 12.0 |
| Santa Fe | — | 28.7 | — | — | — | 28.7 | — | — |
| Sharon kafir | C.I. 813 | 16.1 | 7.7 | 1.8 | 5.8 | 9.0 | 6.8 | 7.9 |
| Standard kafir | C.I. 71 | 25.2 | 8.6 | — | — | 25.2 | 8.6 | 16.9 |
| Texas milo (check) | C.I. 338 | 96.8 | 77.4 | 89.6 | 100.0 | 93.2 | 88.7 | 91.0 |
| Western Blackhull | C.I. 906 | 33.5 | — | — | — | 33.5 | — | — |
| Westland | — | — | — | 12.2 | 23.5 | 12.2 | 23.5 | 17.9 |
| Wheatland (Resistant) | 918 | 25.1 | 20.3 | 17.9 | 21.6 | 21.5 | 21.0 | 21.3 |
| White darso | 52-29 | 16.5 | — | — | — | 16.5 | — | — |
| Witchweed | — | 36.2 | — | — | — | 36.2 | — | — |
| Yellow darso | 31-9 | 11.1 | — | — | — | 11.1 | — | — |
| Forage sorghums: | | | | | | | | |
| African millet | F.C. 9111 | 15.9 | 8.7 | 8.2 | 11.5 | 12.1 | 10.1 | 11.1 |
| Atlas | C.I. 899 | 15.3 | 15.7 | 5.6 | 16.0 | 10.5 | 15.8 | 13.2 |
| Honey | — | 71.3 | 41.4 | 53.5 | 91.0 | 62.4 | 66.2 | 64.3 |
| Honey Sel. | — | 26.4 | 30.4 | 4.9 | 16.9 | 15.7 | 23.7 | 19.7 |
| Leoti | F.C. 6610 | 33.5 | 20.1 | — | — | 33.5 | 20.1 | 26.8 |
| Shallu | — | 68.3 | — | — | — | 68.3 | — | — |
| Sufar drip | — | 19.4 | 16.6 | 6.9 | 6.0 | 13.2 | 11.3 | 12.3 |
| Sumac | F.C. 1712 | 27.1 | 17.4 | 15.4 | 22.8 | 21.3 | 20.1 | 20.7 |
| Sunrise kafir | C.I. 472 | 20.6 | 12.1 | 10.6 | 10.8 | 15.6 | 11.5 | 13.6 |

while the plants were small. In 1947 and 1948, there was a moderate infestation in the Stillwater nursery. However, as the bugs migrated on foot into the nursery in those years, the infestation was not uniform; therefore, reliable data were not obtained. From 1950 to 1953 the chinch bug infestation was not sufficient to cause significant differences between varieties.

The results of these tests are shown in table 1. Most varieties reacted similarly to the chinch bugs at both locations. However, there was a marked difference in the reaction of Hegari in 1949. Kaferita C.I. 811 had the lowest percentage of plants killed at both places. Sharon kafir was more resistant than any of the other kafirs tested. Two selections from crosses of an early dwarf milo, having milo seed characters, appeared to be more resistant in 1949 than any of the other milos tested. These selections were made in 1948 from $F_3$ lines growing in the observational nursery that received a heavy infestation of chinch bugs.

Three combine milos—Wheatland, Westland, and Martin—appeared to be as resistant as Western Blackhull or Hydro kafir and almost as resistant as Standard kafir. Three other combine milos—Midland, Plainsman, and Caprock—were quite susceptible; they should not be planted where chinch bugs are likely to be abundant. Bonita, a dwarf selection from Hegari × Chiltex (Feterita × Kafir), was similar to Hegari in its reaction to chinch bugs. Redlan, a dwarf kafir recently released by the Oklahoma Agricultural Experiment Station, appeared to be highly resistant.

Only nine forage sorghums were included in these tests. Honey and Shallu were very susceptible. Leoti was moderately resistant, while the others were very resistant. A selection of Honey was much more resistant than the original Honey. This resistant Honey is the result of a single-head selection made by the junior author in 1943 from a field at Stillwater, that had been almost completely destroyed by chinch bugs.

### LITERATURE CITED

**Snelling, Ralph O.**, Reginald H. Painter, John H. Parker, and W. M. Osborn. 1937. Resistance of sorghums to the chinch bug. U. S. Dept. Agr. Tech. Bul. 585.

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## A Comparison of Dilute and Concentrate Sprays for Control of Insects of Potato and Tomato[1]

D. O. WOLFENBARGER, *University of Florida Sub-Tropical Experiment Station, Homestead*

A practical method of reducing the amount of water used in pesticidal spray mixtures would tend to lower production costs in several ways. In areas where water is scarce and must be pumped from wells or hauled long distances, a direct saving in time and labor would result from the use of concentrate sprays. Other possible advantages, would be reduced wear on spraying equipment and the more rapid application of pesticidal treatments to check established infestations. A necessary condition to be met in the use of concentrate sprays, however, is that they must control the pest satisfactorily.

Experiments were conducted in 1951–52 and 1952–53 in which comparisons were made between dilute and concentrated spray mixtures. The results of these tests for two seasons on tomatoes and for one season on potatoes are presented.

EQUIPMENT AND METHODS.—Spray machines of the type employed by commercial growers were used as the standard in all experiments. These machines were equipped with booms and varying numbers of nozzles per row. Three nozzles per row were used for young plants. As the plants increased in size the number of nozzles was increased to a maximum of five per row on potatoes and to 11 per row on tomatoes. Pressures of about 425 pounds per square inch were maintained in all experiments. Variable amounts of spray applied per acre, depending on the size of the plants, ranged from 75 to 175 gallons per acre. This equipment is termed the "high-gallonage" sprayer. These machines covered plot widths of 12 feet (four rows of potatoes, two of tomatoes). Plot lengths were as follows: Potatoes, 50 feet; tomatoes, 120 feet (60 plants) in 1951–52, and 36 feet (18 plants) in 1952–53.

A mist-blower sprayer was used for all experiments each season. This self-propelled attachment[2] was bolted to a commercial spray machine and had a rated capacity of 26,000 cubic feet of air per minute with an air speed of 90 miles per hour. Pesticide mixtures piped from the pump of the sprayer were sprayed at pressures of about 300 pounds per square inch into the airstream of the blower. The airstream was directed horizontally toward the plants at right angles to the path of the machine and toward the center of the plots. One-fifth as much water per acre was used with this machine as with the dilute sprayer. This equipment is termed the "mist-blower" concentrate sprayer. Potato spray plots were 96 feet (32 rows) wide for the mist-blower concentrate sprayer. Although the 96-foot width exceeded distances at which the mist-blower was expected to perform satisfactorily, some data were obtained on distances to which the pesticides provided control. Plot sizes for the tomatoes were 120 feet (20 rows) wide and 80 feet (40 plants) long in 1951–52, and 49 feet (seven rows) wide and 36 feet (18 plants) long in 1952–53.

In the 1952–53 season another unit of equipment was used in making concentrate spray applications.[3] It was equipped with a boom holding three nozzles per row for potatoes and four nozzles per row for tomatoes for applying the pesticides. Pressure was adjusted to 80 pounds per square inch. One-fifth as much water per acre was used for dispersing the same amount of pesticide as was used with the high-gallonage sprayer. This equipment was termed concentrate "nozzle" sprayer. Potato plots were 12 feet (four rows) wide and 50 feet long for this machine. Tomato plots were 14 feet (two rows) wide and 36 feet (18 plants) long.

The treatments were replicated four times except with the mist-blower applications. Owing to limitations of space and materials the mist blower applications were not randomized, but duplicate tomato plots and quadruplicate potato plots were treated in 1952–53 with the mist-blower.

Four rows of tomatoes each 60 feet (30 plants) long were left unsprayed as a check in 1951–52. There were four replications of unsprayed check plots in 1952–53, each 14 feet (two rows) wide and 36 feet (18 plants) long.

[1] Florida Agricultural Experiment Station Journal Series, No. 259.

[2] Supplied by F. E. Myers and Brother Company.

[3] Supplied by H. D. Hudson Manufacturing Company.

Fungicides used to control late blight were nabam plus zinc sulphate on potatoes and zineb on tomatoes. Parathion was combined with the fungicide as needed for control of the insects. These were used in the high-gallonage sprayer (per 100 gallons of water) at the following rates: Nabam (18%) 2 qts.; zinc sulphate (36% zn) 12 oz.; zineb (65%) 2 lbs.; parathion, 1 lb. (15%) or ½ pt. of 4 lbs. per gallon of fluid concentrate. As concentrate sprays the same amounts of materials were dispersed in 20 gallons of water, and are termed 5X applications. Ten gallons of water were used for dispersing the same amount of pesticides from the mist-blower on tomatoes in 1951–52; hence, are termed 10X concentrate.

In the 1951–52 experiment on tomatoes an amount of 150 gallons of spray mixture per acre was assumed as the amount used so that 30 and 15 gallons of spray per acre of the 5X and 10X concentrates, respectively, were applied to give approximately the same amounts of active ingredients per acre. In the 1952–53 experiments more exact measurements were made of the dilute spray applications. Forward speeds of machines spraying concentrates were then calculated as those necessary for applying the same amounts of active ingredient per acre as was applied by the high-gallonage sprayer. Necessary and constant speeds were achieved through the use of a low-speed speedometer on the tractor, the accuracy of which was checked with a stopwatch.

All potato and tomato plots were grown from seed planted in November or December. Tomato plants were set in the field in January and the fruit was harvested at the mature-green stage. All plants were given uniform cultural care common to crops in the area.

Serpentine leaf mines, made by larvae of the *Liriomyza pusilla* "complex" were common on potato and tomato plants of all experiments. Aphids, chiefly the green peach aphid, *Myzus persicae* (Sulz.), mixed with a few cotton or melon aphid, *Aphis gossypii* Glov., colonies were present on potatoes. Worm injuries of fruit were attributed mostly to the tomato fruit worm, *Heliothis armigera* (Hbn.), although a light infestation of the fall armyworm *Laphygma frugiperda* (A. & S.), was present on plants in both experiments. Leaf mines and aphids were usually counted on the fourth leaf from the top of the plant. A total of 16 or more leaves was taken as a sample from each treatment. Worm-injured fruits were recorded as percentage of total fruit harvested.

The late blight disease, caused by *Phytophthora infestans* (Mont.) Dby., was active in potato plots but did not appear in the tomato plots.

An accumulation of 0.77 pound technical parathion per acre was applied to the potato plants by the time observations were made for records of aphids and leaf mines and for harvest of the tubers. Pounds of technical parathion per acre applied to tomatoes are given as follows: In 1951–52, 0.68 and 0.90 by March 25 and April 6, respectively; 1.20 by April 15 and 22; in 1952–53, 0.52, 2.06, 2.32 and 2.32 by March 8, April 16, 22, and harvest, respectively.

**Table 1.—Effect of dilute and concentrate sprays of parathion on aphids, serpentine leaf mines and yields of potatoes in 1951–52.**

| Sprayer | Aphids, Average per Leaf on | | Leaf Mines | Bushels of Marketable Tubers per Acre |
|---|---|---|---|---|
| | Feb. 12 | Feb. 20 | Feb. 12 | |
| High-gallonage | 0 | 0 | 0.9 | 351 |
| Concentrate, nozzle | 0 | 0 | 2.8 | 304 |
| Concentrate, mist-blower | 0 | 0 | 4.2 | 306 |

RESULTS.—Results of the potato spray applications pertaining to insects and yield are summarized in table 1.

No aphids were found on any plant sprayed by any machine. Averages of 84.2 and 48.7 aphids per leaf were found, however, on February 12 and 20, respectively, on non-insecticide sprayed plants in a nearby experiment. An average of 22.1 serpentine leaf mines per leaf was found on non-insecticide sprayed plants on February 12. Fewer serpentine leaf mines were found on plants nearer the mist-blower machine path than on plants further from the path. This gradient is shown from the Feb. 12 count as follows:

| Row from machine path | 1 | 3 | 6 | 9 | 16 |
|---|---|---|---|---|---|
| No. mines per leaf | 1.4 | 1.4 | 2.8 | 3.5 | 7.5 |

Slightly more tubers were harvested from dilute than from the concentrate sprayed plants. Tubers harvested from rows 1, 2, 3 and 6 distant from the mist-blower path averaged 334 bushels per acre while those from rows 9, 12 and 16 averaged 288 bushels per acre.

The late blight disease became prevalent in the middle of the plots treated by the mist-blower. Damage by this disease is believed to account for the lower yields in rows 9, 12 and 16. Although late blight was present on plants treated by the other machines it was never abundant and probably did not depress yields appreciably.

Results of the tomato spray applications in the 1951–52 season are summarized in table 2.

**Table 2.—Effect of dilute and concentrate sprays of parathion on serpentine leaf mines and worm-injured fruit on tomato plants in 1951–52.**

| Sprayer | Leaf Mines, Average | | Per Cent Worm Injured Fruit | |
|---|---|---|---|---|
| | Mar. 25 Top Four Leaves | Apr. 6, Fourth Leaf from Top | Apr. 15 | Apr. 22 |
| High-gallonage | 32 | 6 | 2 | 19 |
| Concentrate, mist-blower | | | | |
| 5× | 20 | 10 | 2 | 20 |
| 10× | 17 | 5 | 3 | 20 |
| Untreated | 74 | 32 | 39 | 54 |

Considerable reductions in leaf mines and wormy fruit were obtained by all applications as compared with the check. Differences between sprayers, however, were slight. Late blight was not a factor affecting the plants in this test. No yield data were obtained.

Results of tomato spray applications of the 1952–53 season are summarized in table 3.

Considerable reductions in leaf mines and worm-injured fruit were obtained by all applications as

**Table 3.—Effect of dilute and concentrate sprays of parathion on serpentine leaf mines, worm-injured fruit, and yield of tomatoes in 1952–53.**

| Sprayer | Average Leaf Mines per Leaf | Per Cent Worm-Injured Fruit | | Bushels Marketable Tubers per Acre |
|---|---|---|---|---|
| | | Apr. 16 | Apr. 22 | |
| High-gallonage | 3 | 1 | 4 | 373 |
| Concentrate, mist-blower | 6 | 1 | 13 | 255 |
| Concentrate, nozzle | 7 | 1 | 5 | 209 |
| Untreated | 22 | 38 | 51 | 205 |

compared with the check. Differences between sprayers, however, were slight. Although the most fruit was picked from plants sprayed with dilute spray mixtures, neither late blight, insect control nor plant injury serve to give an explanation for the yield differences between sprayer treatments.

SUMMARY.—Reduction of aphids and serpentine leaf mines on potatoes and of leaf mines and worm-injured fruit on tomatoes were achieved almost as well with concentrate as with dilute spray mixtures. Concentrate sprays applied by means of a mist-blower or by nozzles were practically equal in insect control.

## Repellency of Toxaphene Dust and Parathion Spray to *Nomia melanderi* in Blossoming Alfalfa

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Numerous seed growers and some field men in the lower Yakima Valley have indicated that a 10 or 15 per cent toxaphene dust applied to blossoming alfalfa would repel alkali bees (*Nomia melanderi* Ckll.) for 3 to 7 days. Some seed growers also believe that parathion spray or dust will repel bees for a sufficient length of time, 2 to 3 days, so when it is applied to a field in bloom it will kill but few pollinators.

Linsley and McSwain (1947) reported that DDT and DDT-fused sulphur dusts were repellent to honey bees for a few days, but insufficient information was obtained to indicate their effect on wild bees.

Field locations where the toxaphene dust was applied by ground equipment before 6:00 A.M., were all within 500 feet of a very large alkali bee nesting site. This site provides a very adequate supply of pollinators for all the seed fields dusted with toxaphene. Bee populations and tripping records were taken between noon and 2:00 P.M. for all the toxaphene studies. Populations were determined by counting the number of bees in an estimated square yard selected at random approximately 3 yards in front of the observer; then the area counted was approached cautiously and the alfalfa moved to obtain records of bees working under the foliage. After this, the observer walked another 8 to 10 paces and repeated the count until 40 samples had been taken from each field. Two collections of 40 sweeps each were also taken by passing a standard 15-inch sweeping net in a straight line in front of the sampler while walking slowly through the field. Tripping[1] data were recorded by counting freshly tripped florets and then opened untripped florets on 100 racemes taken at random in each field. This was done at the same time populations were recorded. The results are given in table 1.

There was little change in populations or tripping rates (Table 1) from 6 hours to 3 days after toxaphene was applied. Perhaps in areas where alkali bees are not numerous a more obvious repellency occurs.

For the parathion test a 110-acre alfalfa seed field was used. It had a severe pea aphid infestation and was in full bloom. Since it was in an isolated region of the Yakima Valley, the native bee poisoning could be studied effectively. The field was sprayed by air at 6:00 P.M. on August 2, with 10 ounces of actual parathion in 5 gallons of water per acre. It was warm and quiet with no appreciable drift. There was no bee activity at the alkali bee nesting site after 5:00 P.M., therefore bees probably were not poisoned by direct contact.

Alkali bees nested along the roadside which bordered the sprayed field on two sides. In an intensive nesting area 6 plots, 1 yard square, were marked off with a few yards between each one. After the dead bees had been counted in these plots all the bee tunnel entrances were pinched closed on the soil surface; a technique of Bohart & Lieberman (1949). Late afternoon, each day, nesting activity data were recorded. The number of opened tunnels were counted and again pinched closed; also the number of dead bees was recorded.

The average number of bees found in the field and the percentage of florets tripped are recorded in table 1. Table 2 gives the counts made at the nesting site. Since there was an appreciable mortality and extensive tripping (23 per cent) in the parathion-treated field the day after application, repellency

[1] Release of the sexual column from the keel petal.

**Table 1.—Repellency of toxaphene and parathion to the alkali bee. Wapato, Washington, 1953.**

| Application Date[1] | No. Bees per Acre | | | Per Cent Florets Tripped | | | No. Bees per 40 Sweeps[2] | | |
|---|---|---|---|---|---|---|---|---|---|
| | 8-1 | 8-2 | 8-3 | 8-1 | 8-2 | 8-3 | 8-1 | 8-2 | 8-3 |
| July 31 | 2,904 | 2,420 | 3,388 | 70 | 70 | 73 | 7.5 | 8 | 2 |
| Aug. 1 | 3,872 | 3,872 | 2,904 | 71 | 81 | 78 | 8 | 5 | 8 |
| Aug. 3[2] | 2,904 | 2,904 | 1,452 | 77 | 67 | 85 | 14 | 4.5 | 11.5 |
| Check | | | 2,420 | | | 80 | | | 8.5 |
| Aug. 2 | | 1,452 | 484 | | 25 | 23 | | 4 | |

[1] Toxaphene dust applied July 31, Aug. 1 and 3; parathion spray applied Aug. 2.
[2] Check until treated.
[3] Average of two counts.

was probably not a significant factor. Only a few bees were counted in this field on August 3, however the tripping records showed there was good activity earlier. By early afternoon the day following the parathion application one could hear intense hyperactivity in the nests. There was a most unusual constant high pitched hum all over the bee site.

The great variation in the number of bees counted by the sweeping technique (Table 1) emphasizes its limitations where this native bee is concerned. Since this species is easily disturbed a more accurate measure of bee activity in an alfalfa field may be obtained with tripping records and area counts instead of sweeping.

From the limited studies made it appears that 15 per cent toxaphene dust applied at 30 pounds per acre on blossoming alfalfa has little effect on alkali bee activity. Ten ounces of parathion spray per acre applied on a blooming alfalfa field in the evening did not give sufficient repellency to prevent poisoning of approximately 30 per cent of the alkali bees nesting nearby. This is apparently the first report indicating toxicity of parathion to alkali bees under field conditions.

**Table 2.—Alkali bee nests following application of parathion to blossoming alfalfa. Wapato, Washington. 1953.**

| Date | Average Number in 6 Square Yards | | Per Cent Reduction in Active Nests |
|---|---|---|---|
| | Dead Bees | Active Nests | |
| Aug. 2 | 7 | 126 | 0 |
| Aug. 3 | 36 | 120 | 5 |
| Aug. 4 | 18 | 78 | 39 |

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## Control of Human Bot Fly on Cattle[1]

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The human bot fly, *Dermatobia hominis* (L., Jr.)[2], is a common important ectoparasite of cattle in Mexico, Central and South America and the Carribean area. The presence of this parasite in the tissues of cattle causes losses including reduction in weight gains, reduced milk flow and damage to hides. In addition, attacks by the torsalo larvae causes an animal to be more susceptible to pathogenic infections and to secondary infestations by other parasites, such as the screw worm fly, *Callitroga hominivorax* (Coquerel).

In recent years a number of intensive field trials have been conducted to find a safe and effective insecticide that could be applied to cattle for the control of this parasite. Squibb (1945) at the Inter-American Institute of Agricultural Sciences, Turrialba, Costa Rica, tried weekly spray applications of DDT and rotenone. This investigation was followed by those of Rhoad[3], who found that the daily application of the water extract of the green root of derris was an effective control agent. In 1949 Creighton and Neel, working at this same institution, tested some of the newer insecticides including DDT, toxaphene, chlordane and BHC.

Laake (1948) in Brazil demonstrated the use of 0.5 per cent toxaphene spray and dip as an effective control agent of this parasite. Adams (1952) and his associates in Nicaragua have demonstrated further that the systematic spraying of cattle with 0.5 per cent toxaphene on an area-wide basis can minimize the damages caused by this pest. Toledo (1952) in Brazil applied BHC and lindane as dusts and BHC and toxaphene as sprays to determine if the biweekly treatment of cattle with these materials would give adequate torsalo control during the rainy season, December through March. Pinheivo & Baroni (1953), also working in Brazil, found that the biweekly spraying of cattle with 0.4 per cent toxaphene and .016 per cent gamma isomer of BHC over a 1-year period resulted in the economic use of pastures which previously were non-utilizable because of heavy populations of this fly.

Description and Life Cycle.—The adult is a relatively large, blue, metallic-colored fly measuring from 10 to 15 mm. in length. It is seldom encountered in the field and is rarely, if ever, captured by conventional fly trapping methods. When fully developed the larva measures 25 mm. in length.

The life cycle is completed in about 3 months, depending on the temperature, and can be summarized as follows: egg stage, 5 to 12 days; larval period in the egg case on the intermediate host, 1 to 20 days; larval period in the definitive vertebrate host, 34 to 43 days; pupal stage, 35 to 43 days; life span of the adult, 5 to 10 days. The different stages of the insect are found throughout the year, but the peak incidence occurs during the rainy season.

Materials and Methods.—The animals selected for this experiment were 40 *criollo* and Brahma steers located on Finca Azul near Turrialba, Costa Rica. Selections were made so that animals with heavy, medium, and light infestations were divided equally into 4 groups of 10 animals each. The groups were selected at random for the treatments. The 4 groups were maintained in separate pastures. The pastures, located on rolling and sometimes steep terrain, were only partially cleared of trees and woody shrubs. Grasses and other vegetation were abundant everywhere. This test was conducted during a period of heavy rainfall from September 30, 1952, to January 20, 1953. This is considered to be the latter part of the rainy season which, in the Turrialba area, extends approximately from May to the latter part of January.

The insecticides were applied with a power sprayer at a pressure of from 250 to 300 pounds per square inch. A 4-foot spray gun equipped with three nozzles was used for applying the insecticides. The sprayer

[1] This study, made possible by a grant from the Standard Oil Development Co. of Linden, New Jersey, was performed at the Inter-American Institute of Agricultural Sciences, Turrialba, Costa Rica. It was approved by the investigator's graduate committee of Texas Agricultural and Mechanical College as part of a dissertation problem.

[2] Commonly referred as torsalo fly in Latin America.

[3] Rhoad, A. O. 1946–47. Control of torsalo, *Dermatobia hominis* (L., Jr.), in cattle. Unpublished. Annual Report of the Inter-American Institute of Agricultural Sciences, Turrialba, Costa Rica.

was arranged to pump from drums filled with the insecticides. The drums were cleaned thoroughly after each material was applied to prevent contamination. An average of 3 quarts of the spray was applied to each animal. The testing of more than 3 insecticides was not possible because of the small number of pastures available. Toxaphene was selected as one material because it has been established as a safe and fairly effective control agent. The combination DDT and BHC was selected because preliminary experiments in the past indicated that both materials were effective control agents. The fact that aldrin could be used economically and effectively at a very low concentration was the prime factor for including it in the group. The 0.5 per cent toxaphene and 0.15 per cent aldrin treatments were prepared respectively from toxaphene and aldrin emulsifiable concentrates of 50 per cent and 25 per cent. The combination of 0.5 per cent DDT and 0.03 per cent gamma isomer of BHC was prepared from a wettable powder concentrate containing 38.1 per cent DDT and 2.3 per cent gamma isomer of BHC.

The treatments were applied every 2 weeks. Because previous examinations indicated that the infestation by this parasite on one side of each animal represented about one-half the number of total infestation, all counts were taken arbitrarily from the left side of each animal. Counts were made previous to the spray applications once every 2 weeks until October 28 and, thereafter, once every 4 weeks until the end of the experiment. Each group comprised ten animals until December 23rd. During the remainder of the time each of the groups lost by sale the following number of animals: toxaphene, two; DDT-BHC, two; aldrin, none; and check, one.

RESULTS.—The results of this study are shown in table 1. The analysis of variance showed that: (1) all treatments were significantly better than the unsprayed, and (2) differences between insecticides were not significant.

This study was conducted during a period of slight decrease in the incidence of human bot fly infestations. Even though a noticeable reduction of this fly occurred in the untreated group, the economic importance of the high infestation rate of this group at the end of this experiment remained quite obvious. During this same period the treatments reduced the infestation of the animals to a point of minor significance.

In contrast to a consistent infestation rate decrease among the toxaphene and aldrin treated groups, a slight infestation rise during the first 4 weeks in the DDT-BHC treated group can be noted upon examining table 1.

**Table 1.—The control of Dermatobia hominis (L., Jr.) on cattle by the use of three insecticides during the period September 30, 1952 to January 20, 1953. Turrialba, Costa Rica.**

| Application Dates | Average Number[1] of Larvae Established per Animal (Left Side Only) | | | |
|---|---|---|---|---|
| | Toxaphene 0.5 Per Cent | DDT Plus Gamma Isomer of BHC 0.5 Per Cent plus 0.03 Per Cent | Aldrin 0.15 Per Cent | Check |
| 9-30-52 | 32.0[2] | 30.9[2] | 33.4[2] | 31.5[2] |
| 10-14-52 | 26.8 | 36.3 | 29.3 | 37.4 |
| 10-28-52 | 25.7 | 31.4 | 28.3 | 40.8 |
| 11-11-52 | | | | |
| 11-25-52 | 10.4 | 12.3 | 9.4 | 20.9 |
| 12- 9-52 | | | | |
| 12-23-53 | 6.0 | 5.9 | 4.7 | 17.8 |
| 1- 6-53 | | | | |
| 1-20-53 | 3.5 | 4.5 | 2.4 | 22.0 |
| Average | 14.45 | 18.08 | 14.84 | 27.87 |

Least significant difference between treatments at .05 level =6.43.

[1] Represents the average of from 8 to 10 animals.
[2] Initial infestation.

SUMMARY.—A comparative insecticide test during the period September 30, 1952, to January 20, 1953, in the vicinity of Turrialba, Costa Rica, showed that insecticide concentrations of 0.5 per cent toxaphene, a mixture of 0.5 per cent DDT and 0.03 per cent gamma isomer of BHC, and 0.15 per cent aldrin when sprayed on cattle at bi-weekly intervals gave effective control of the human bot fly. The differences in control among the insecticides were not significant.

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## Insecticides for Cotton Leafworm Control in 1952 and 1953

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Infestations of the cotton leafworm, *Alabama argillacea* (Hbn.), were of minor importance in central Texas during 1952 and 1953. However, damaging infestations in occasional fields late in each season afforded an opportunity for tests with several insecticides for the control of this insect in the vicinity of Waco, Tex.

PROCEDURE.—Experiments 1 and 2 were conducted in August 1952 and the other experiments late in August and during the first half of September 1953. The plots in experiments 1, 2, and 3 ranged from 2 to 6 acres in size. Those in the other experiments were only 0.1 acre, because the heaviest infestations occurred in a low, narrow area extending

[1] In cooperation with the Texas Agricultural Experiment Station.

across the fields. The use of the small plots also permitted more treatments to be included. There were no replications of treatments.

In the large-plot experiments emulsions were applied with 8-row tractor-attachment low-pressure and low-volume spray machines at the rate of 6 gallons per acre. In the small-plot experiments they were applied with a 4-row tricycle-type self-propelled machine constructed especially for spraying small areas; an engine mounted on the frame was used to propel the machine and to drive the pump. The total volume of spray applied per acre was 7.5 gallons. Three nozzles per row were used, and the sprays were applied at a pressure of 60 pounds per square inch. Dusts were applied with rotary hand guns.

**Table 1.—Effectiveness of several insecticides against the cotton leafworm in field experiments.**

| Treatment (Per Cent in Dusts, Pounds of Active Ingredient per Acre in Sprays) | Dosage per Acre | Number of Larvae per Plant Before Treatment | Per Cent Control After— | |
|---|---|---|---|---|
| | | | 24 Hours | 48 Hours[1] |
| *Experiment 1* (Sprays applied August 8, 1952) | *Gallons* | | | |
| Toxaphene 1.5 | 6 | 9 | 96 | 98 |
| Endrin 0.2 | 6 | 7 | 88 | 100 |
| EPN 0.125 | 6 | 6 | 98 | 100 |
| *Experiment 2* (Sprays applied August 14, 1952) | | | | |
| Toxaphene 1.5 | 6 | 17 | 89 | 97 |
| Endrin 0.2 | 6 | 15 | 97 | 97 |
| 0.3 | 6 | 18 | 97 | 98 |
| Isodrin 0.2 | 6 | 17 | 88 | 95 |
| 0.3 | 6 | 17 | 94 | 98 |
| EPN 0.125 | 6 | 15 | 99 | 99 |
| 0.25 | 6 | 19 | 99 | 99 |
| Parathion 0.125 | 6 | 20 | 100 | 100 |
| Metacide 0.16 | 6 | 19 | 99 | 100 |
| *Experiment 3* (Sprays applied August 26, 1953) | | | | |
| Toxaphene 2.25 | 6 | 19 | 90 | 99 |
| 1.5 | 6 | 24 | 84 | 90 |
| Endrin 0.3 | 6 | 28 | 97 | 100 |
| 0.2 | 6 | 20 | 95 | 98 |
| Parathion 0.25 | 6 | 25 | 99 | 100 |
| Chlorthion 0.375 | 6 | 25 | 96 | 99 |
| 0.25 | 6 | 29 | 85 | 94 |
| *Experiment 4* (Dusts and sprays applied August 29, 1953)[2] | *Pounds* | | | |
| Dusts: | | | | |
| Toxaphene 20+sulfur 40 | 10 | 13 | — | 27 |
| BHC gamma 3 +DDT 5+sulfur 40 | 13 | 17 | — | 46 |
| Sprays: | *Gallons* | | | |
| Toxaphene 2.25 | 7.5 | 13 | — | 85 |
| BHC gamma 0.3 +DDT 0.5 | 7.5 | 17 | — | 80 |
| Endrin 0.3 | 7.5 | 17 | — | 97 |
| *Experiment 5* (Dusts applied September 2, 1953)[3] | *Pounds* | | | |
| Toxaphene 20+sulfur 40 | 18 | 16 | 66 | — |
| BHC gamma 3 +DDT 5+sulfur 40 | 18 | 20 | 66 | — |
| Calcium arsenate | 10 | 19 | 73 | — |
| *Experiment 6* (Dusts applied September 18, 1953)[4] | | | | |
| Toxaphene 20+sulfur 40 | 13 | 15 | 60 | 91 |
| BHC gamma 3+DDT 5+sulfur 40 | 17 | 17 | 62 | 80 |
| Calcium arsenate | 11 | 16 | 74 | 98 |

[1] After 72 hours in experiment 1.
[2] Heavy shower after 4 hours, 1 inch of rain within 30 hours.
[3] 1 inch rain after 8 hours.
[4] Trace of rain after 4 hours.

Infestation records were made by tagging 10 plants selected at random within each plot and counting all the leafworm larvae on each plant just before treatment, 24 and 48 hours after treatment, and sometimes at longer intervals after treatment. Since reports of failures by growers to control leafworms with toxaphene and BHC plus DDT dusts were received during 1953, these materials were included in three experiments. Treatments and results in the various experiments are given in table 1.

Results.—The cotton plants averaged 3.5 feet in height in 1952 and 4.5 feet in 1953. In experiments 1 and 3 the population consisted of larvae of all sizes, but in the other experiments most of the larvae were large.

In experiment 1 all the treatments gave good initial kill of leafworms. The cotton continued to be succulent and therefore was subjected to reinfestation. Six days after treatment toxaphene still showed 93 per cent control and endrin 58 per cent, but EPN was ineffective after 5 days.

In experiment 2 all insecticides gave good control. Isodrin was slightly less effective at 0.2 pound than at 0.3 pound per acre. There was no appreciable difference between these two dosages of endrin, or between 0.125 and 0.25 pound of EPN. Parathion at 0.125 pound per acre gave 100 per cent kill after 24 hours and Metacide at 0.16 pound after 48 hours.

In experiment 3 endrin at 0.3 pound and parathion at 0.25 pound per acre gave complete kill 48 hours after treatment. Toxaphene at 2.25 pounds, endrin at 0.2, and chlorthion[2] at 0.375 pound per acre were only slightly less effective. Toxaphene at 1.5 pounds and chlorthion at 0.25 pound per acre were less effective.

In experiment 4 toxaphene and BHC plus DDT applied in dusts and sprays and endrin applied in a spray were compared. The amount of toxicant applied in the dust differed very little from that in the spray, being slightly in favor of the toxaphene spray and of BHC plus DDT in the dust. There was a heavy shower 4 hours after treatment, and about 1 inch of rain fell on the field in several showers within 30 hours. Toxaphene and BHC plus DDT gave considerably better control in sprays than in dusts. Endrin gave outstanding control under the existing adverse weather conditions.

In experiment 5 heavy dust applications of toxaphene plus sulfur, BHC plus DDT plus sulfur, and calcium arsenate were compared. About 1 inch of rain fell 8 hours after treatment. After 24 hours the kill with calcium arsenate was slightly higher than with the organic insecticides.

The same dusts used in experiment 5 were used in experiment 6 in an attempt to compare their performance under favorable weather conditions. The dosages of BHC plus DDT and of calcium arsenate were heavy, but that of toxaphene was less than is normally used for leafworm control. After 48 hours calcium arsenate gave nearly complete control, and toxaphene was more effective than BHC plus DDT.

[2] O,O-Dimethyl-O-(3-chloro-4-nitrophenyl)-thiophosphate.

## Effect on Beneficial Insects of Several Insecticides Applied for Cotton Insect Control[1]

R. C. GAINES, *U.S.D.A., Agr. Res. Serv., Entomology Research Branch*[2]

The purpose of this work was to determine the effect on beneficial insects and spiders of certain insecticides applied for control of cotton insects. All treatments were made by airplane during the early morning. One application was made on July 7 for control of the cotton fleahopper, *Psallus seriatus* (Reut.). Applications for control of the boll weevil, *Anthonomus grandis* Boh., were started 3 weeks later, on July 28. Ten applications 4 or 5 days apart were required from July 28 to September 3. Each

[1] Presented at the meeting of the Cotton States Branch, Entomological Society of America, at Biloxi, Miss., Jan. 25–27, 1954.

[2] The field work was performed by C. C. Bowling, J. O. Gibson, Jr., and R. L. Watson.

**Table 1.—Effect on beneficial insects and spiders of certain insecticide dusts applied for the control of cotton insects.**

| Record Date | Number per 150 Row Feet–Per 100 Sweeps | | | | | | |
|---|---|---|---|---|---|---|---|
| | Lady Beetles | Flower Bugs | Lacewing | *Geocoris* | Assasin Bugs | Spiders | Syrphids |
| *Field 1 (37 acres)—Dieldrin 1.5%+DDT 5%+sulfur 40%* | | | | | | | |
| June 15 | 15 | 138 | 7 | 1 | 0 | 13 | 0 |
| 17 | 16-3 | 402-10 | 4-1 | 1-1 | 0-0 | 22-1 | 0-0 |
| 22 | 15-4 | 393-24 | 9-1 | 4-2 | 0-0 | 25-2 | 0-0 |
| 29 | 33-1 | 210-13 | 5-1 | 4-1 | 0-1 | 54-3 | 0-1 |
| July 6[1] | 18-3 | 186-15 | 6-1 | 10-2 | 0-0 | 84-11 | 0-1 |
| 7[2] | 21-1 | 81-3 | 0-0 | 3-1 | 0-0 | 42-2 | 0-0 |
| 13, 14 | 28-2 | 72-5 | 2-1 | 2-1 | 0-0 | 66-6 | 0-1 |
| 20, 21 | 59-6 | 95-7 | 9-1 | 4-2 | 1-0 | 64-4 | 0-0 |
| 27, 28 | 54-12 | 69-14 | 2-1 | 2-4 | 1-0 | 63-13 | 0-0 |
| Aug. 3 | 29-1 | 7-1 | 9-1 | 0-1 | 1-0 | 1-0 | 0-0 |
| 10, 11 | 9-2 | 9-2 | 11-2 | 0-0 | 0-0 | 6-1 | 0-0 |
| 17, 18 | 4-3 | 0-1 | 0-1 | 0-0 | 0-0 | 0-1 | 0-1 |
| *Field 2 (34 acres)—Toxaphene 20%+sulfur 40%* | | | | | | | |
| June 15 | 8 | 187 | 3 | 1 | 0 | 25 | 0 |
| 17, 18 | 9-2 | 447-19 | 2-1 | 1-1 | 0-0 | 18-2 | 0-0 |
| 23 | 14-3 | 253-17 | 9-1 | 0-1 | 0-0 | 45-2 | 0-0 |
| 30 | 19-3 | 144-11 | 0-1 | 0-1 | 0-1 | 45-5 | 0-0 |
| July 7, 8 | 33-1 | 124-7 | 1-0 | 4-1 | 2-0 | 47-2 | 0-0 |
| 14, 15 | 40-4 | 67-7 | 2-1 | 4-0 | 0 0 | 43-3 | 0-1 |
| 22 | 77-10 | 151-10 | 5-1 | 1-1 | 0-0 | 47-4 | 0-0 |
| 28, 29 | 33-3 | 26-4 | 4-0 | 1-1 | 0-0 | 15-2 | 0-0 |
| Aug. 4, 5 | 15-3 | 18-2 | 4-1 | 0-0 | 0-0 | 2-1 | 0-0 |
| 11, 12 | 2-1 | 0-1 | 7-1 | 0-0 | 0-0 | 1-0 | 0-1 |
| 18, 19 | 0-1 | 0-0 | 1-0 | 0-0 | 0-0 | 0-0 | 0-0 |
| *Field 3 (51 acres)—BHC (gamma 3%)+DDT 5%+sulfur 40%* | | | | | | | |
| June 16 | 23 | 153 | 4 | 1 | 0 | 13 | 0 |
| 18, 19 | 12-7 | 230-14 | 6-1 | 0-1 | 0-0 | 22-2 | 0-0 |
| 24 | 19-5 | 224-16 | 1-1 | 0 0 | 0-0 | 19-2 | 0-0 |
| July 1 | 24-3 | 120-12 | 0-0 | 1-1 | 0-0 | 64-5 | 0-0 |
| 8, 9 | 9-1 | 58-6 | 1-0 | 0-1 | 0-0 | 15-2 | 0-0 |
| 15, 16 | 23-4 | 111-9 | 3-1 | 3-1 | 0-0 | 43-8 | 0-1 |
| 22, 23 | 82-16 | 231-19 | 3-1 | 6-1 | 1-0 | 61-8 | 0-0 |
| 29, 30 | 25-2 | 13-2 | 2-0 | 0-0 | 0-0 | 2-2 | 0-0 |
| Aug. 5, 6 | 6-2 | 15-1 | 10-2 | 0-0 | 0-0 | 0-1 | 0-0 |
| 12, 13 | 15-3 | 0-1 | 6-1 | 0-0 | 0-0 | 1-0 | 0-1 |
| 19, 20 | 3-0 | 0-1 | 1-0 | 0-0 | 0-0 | 1-1 | 0-0 |
| *Field 4 (60 acres)—BHC (gamma 3%)+DDT 5%+sulfur 40% and calcium arsenate* | | | | | | | |
| June 16 | 29 | 387 | 1 | 0 | 0 | 17 | 0 |
| 19 | 17-4 | 482-20 | 2-2 | 1-2 | 0-0 | 22-4 | 0-0 |
| 25 | 11-3 | 343-18 | 0-1 | 1-1 | 0-0 | 37-3 | 0-0 |
| July 2 | 45-3 | 223-18 | 2-0 | 3-1 | 0-0 | 90-5 | 0-0 |
| 9, 10 | 9-3 | 61-4 | 1-1 | 2-1 | 0-0 | 25-2 | 0-1 |
| 16, 17 | 31-3 | 91-23 | 7-1 | 8-2 | 1-0 | 49-7 | 0-1 |
| 23, 24 | 53-12 | 88-10 | 3-1 | 5-4 | 0-0 | 52-10 | 0-0 |
| 30, 31 | 7-2 | 5-2 | 2-1 | 2-0 | 0-0 | 6-1 | 0-0 |
| Aug. 6, 7 | 3-1 | 4-1 | 4-1 | 0-0 | 0-0 | 3-1 | 0-0 |
| 13, 14 | 2-1 | 1-1 | 2-0 | 0-0 | 0-0 | 0-0 | 0-1 |
| 20, 21 | 0-1 | 1-1 | 0-1 | 0-0 | 0-0 | 0-1 | 0-1 |

[1] Average for 4 points.

[2] Average for 2 points. Poison applied at 5 a.m. on July 7.

insecticide was applied at 8 pounds per acre on July 7; 10 pounds on July 28 and August 1; 12 pounds on August 5, 10, 14, and 18; and 15 pounds on August 22, 26, 30, and September 3. All injurious pests were effectively controlled with each treatment.

The records of beneficial insects were made by examining the plants on 25 row feet and by making 100 sweeps with a 16-inch net at six points in each of the four fields. The results of these tests are shown in table 1.

The single insecticide application made on July 7 greatly reduced the beneficial insect populations. There was a considerable build-up before the next application was required 3 weeks later, on July 28. After the second to fourth application had been made in the regular boll weevil poisoning program, beneficial insect and spider populations were practically eliminated.

## A Migration of *Aedes vexans* Meigen[1]

WILLIAM R. HORSFALL,
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The swamp mosquito, *Aedes vexans*, is well known as a migratory species. Observations of Hearle (1926) in Canada and Stage *et al.* (1937) in the Pacific Northwest indicate that flights of 10 to 30 miles from larval sites are common occurrences, but shorter flights of 1 to 6 miles are also known. Limited migrations are in the manner of creeping spread during which the mosquitoes keep close to the ground. An instance reported by Rees (1943) at Salt Lake City, Utah, showed that in 2 to 5 days a creeping flight had spread over the city for a distance of 5 miles from the nearest possible source. Under some conditions adults of this species fly at higher altitudes and are often distributed rapidly. MacCreary (1941) trapped migrants at elevations of 80 feet above the ground. Glick (1939) trapped night-flying females at 500 feet and 1000 feet above the ground.

An extensive invasion into Illinois was made by *Aedes vexans* during the early part of September, 1953. Attention of this laboratory was called to the presence of annoying infestations of this mosquito at several places in central and northern Illinois during the week of September 4 to 11, 1953. A hasty survey extending from the valley of the Illinois River near Havana eastward through the valley of the Sangamon River and as far east of the Wabash Valley showed infestations comparable to local summer populations. No *Aedes vexans* had been collected from this area during any of several collecting trips made during August. This mosquito develops in sites subject to transient inundation, but no such conditions prevailed anywhere in the area. Neither the rivers nor their tributaries had been in flood during the preceding 2 months. In fact, the rivers had fallen steadily during the interval as a result of a statewide deficiency in rainfall second only to that of 1893 in the annals of recorded weather for the state (Climatological Data, Illinois, 58(8): 90). Obviously, the mosquitoes did not originate within the state. Neither did they come from any area to the south, west or east where dry climatic conditions prevailed.

Logical sources of a population large enough to extend over the hundreds of square miles known to have been infested were in Wisconsin. Heavy rains causing suitable conditions for producing large populations of this species occurred during the first 4 days of August over one area involving parts of Juneau, Sauk, Columbia, Adams and Marquette counties and a smaller area to the south and east in Waukesha and Milwaukee counties (Climatological Data, Wisconsin 58(9): 122). Centers of these areas are about 230 miles north of that surveyed in central Illinois. During the latter part of August and the first 3 days of September, unseasonably hot and dry weather prevailed over southern Wisconsin (*idem.*). The heat wave ended during the evening of September 3 when a massive cold front moved across Wisconsin and blanketed Illinois September 4. The cold front was accompanied by a general displacement of air without excessive turbulence.

Coincident with the invasion of the cold air came a large flight of the mosquitoes to the metropolitan area of Chicago at least 90 miles south of the Waukesha and Milwaukee counties. Complaints about annoying populations of mosquitoes came from hunters in central Illinois beginning September 7. Presumably these mosquitoes had been displaced southward for distances of 90 to 230 miles within 24 to 48 hours. Some females were collected as far away as the southern tip of Illinois September 16 where none had existed in August. If these mosquitoes also invaded with the advancing cold front, they travelled some 460 miles or more.

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[1] Contribution from the Department of Entomology, University of Illinois.

**ANNOUNCEMENT: ENTOMA, EDITION 10**

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# EDITORIAL

## One Hundred Years of Entomology—Past and Future

The first professional entomologists of the United States were appointed 100 years ago. Today this nation has approximately 4,500 professional entomologists. These scientists have the responsibility of protecting our resources from insect damage.

Few people know about the total destruction brought about by pest insect species. They are unaware of the important role of insects in the spread of diseases of man, animals, and plants. Even fewer know of the true value of the beneficial species. Our nation knows comparatively little about the science of entomology.

One of the speakers at an entomological meeting several years ago pointed out that not one person out of a hundred knew what an entomologist was, or what one did. It is perhaps understandable why so few people know what an entomologist is when we consider how few entomologists there are —about one to 36,000 in relation to the total population of our country.

Prominent entomologists and insecticide chemists have pointed out through published articles and informal addresses during recent months what entomology has meant in the past 100 years to the production of food, feed, and fiber, the protection of man and animals from attack by insects, and the diseases transmitted by such insects. It is estimated, I believe conservatively, that at least 10 per cent of the production from our soils are destroyed by insects. We can only speculate what these losses would be without the entomological information developed during the past 100 years. Certainly our agricultural industry, and in turn the nation's economic position, would not be what it is today. Entomologists have assumed their responsibility of preventing or reducing insect losses in years past with limited financial support. Thousands of dollars have been added to our national income for each dollar spent on research, teaching, extension, control, quarantine, and other activities dealing with insects.

Millions of people have been spared suffering caused by insect-borne diseases. Insects carry many kinds of diseases including some of the most important and devastating diseases of man. Research by entomologists, chemists, and medical specialists led to effective control of malaria, the world's worst disease, by developing ways to control the mosquito vectors. Typhus, transmitted by the body louse, probably has caused more deaths during all wars prior to World War II than enemy action. Billions were spent developing means of protecting lives of individuals from implements of war over the years. Yet during that same period of time, funds devoted for research to control lice, the vectors of typhus, hardly exceeded a million dollars.

The achievements of entomologists in the production of food have been as spectacular. Fruit and vegetable growers fully realize that without present methods of controlling various insects, it would not be possible to grow many of our fruits and vegetables on a commercial scale. Cotton growers know that this crop could not be produced profitably in the United States today without the available methods of combatting the many insect pests of cotton. The livestock industry would not be flourishing, particularly in the South, without the progress made in controlling ticks, flies, screw-worms, and other external parasites.

Many of us are aware that our achievements in entomology have not been adequately publicized. Committees of the Entomological Society of America, and many individuals in state, federal, and industrial institutions have and are doing an excellent job to inform the public of these achievements during this 100th anniversary. But I doubt if the true significance of past accomplishments can be brought home to the public in 1 year and we should particularly continue to keep the public informed of the role of entomology in the nation's welfare.

We must acknowledge the contributions of many insect specialists for the status of our present information. Many naturalists, and many trained taxonomists developed a foundation of knowledge necessary to develop control measures before the first positions of professional entomologists were created. Many other entomologists devoted their study to the life history

and habits of insects. Information resulting from such study often provides the key for developing practical control measures.

There are several well proved methods by which an insect might be controlled. These include: 1, cultural control; 2, biological control; 3, development of varieties resistant to insect attack; and 4, chemical control. Few of us realize the amount of thought and pioneering research effort necessary on the part of early entomologists in determining that these approaches to insect control most likely would lead to success. We can rightfully claim outstanding progress in meeting insect problems. But entomologists fully recognize that many unsolved problems still are before us.

We can only speculate what entomology as a science will accomplish in the next 100 years. Past experience and developments will serve as a solid foundation upon which to continue making progress. In attacking entomology problems in the future, we have great advantages over those who pioneered in entomological work 100 years ago. Let us review our present position with that of our first professional entomologists. Today, we draw upon new information gained in many fields of science, including chemistry, physics, engineering, medicine, physiology, pathology, agronomy, pharmacology, and many other sciences. A larger number of specialists in these fields cooperate and actively participate in the solution of entomological problems. We have a vast amount of information on the taxonomy, life history, habits, and ecology of hundreds of insect pests. Almost every state institution has qualified and experienced teachers to train corps of specialists needed to attack almost any phase of the insect problem. The entomologists have just recently organized a single national society—The Entomological Society of America—which can do much more to advance entomology than was possible in the past. Federal and state institutions have personnel and facilities to provide greater assurance against the introduction of new pests equally as destructive as some of our worst pests introduced during the past century. We are better prepared to detect incipient outbreaks and have the know-how to delay or prevent the spread of many insects. We have well-equipped entomology research laboratories in nearly all state experiment stations. Federal agencies have research stations located throughout the nation. Our industrial firms can furnish the chemicals and equipment needed to meet many entomological problems. The nation has many pest control operators with equipment and experienced personnel available to deal immediately with a wide variety of insect problems. There is more cooperation and coordination of effort between federal, state, and industrial institutions. The public and growers are depending more and more on entomologists for guidance in reducing or preventing losses caused by insect pests. All these advantages have accrued during the past 100 years.

In spite of the great progress we have reason to wonder sometimes whether new insect problems develop as rapidly as older problems are solved. There are many reasons why this seems so. Insects are capable of changing their habits and adapting themselves to exist on new crops. They become established in new areas. The significance of acquired resistance to insecticides has been forceably brought to our attention during recent years. The public demands higher standards of insect control. The grower has learned to expect insect forecasts and more specific advice as to when and what control measures should be used. The use of a wider variety of chemicals on a more extensive scale has multiplied the problem of avoiding the contamination of our food supply with hazardous chemical residues. We must continue to develop effective and practical ways to use these chemicals with complete assurance that there will be no adverse effects on the safety and quality of food products.

It is essential that all phases of entomology—research, control, quarantine, teaching, and extension receive adequate financial support to meet these many problems. How can we impress the public so the needed support will be provided? One over-all selling job is essential. If unsuccessful, this factor will be the greatest deterent to progress in entomology during the next 100 years. I refer to the job of convincing the public that we can serve the nation more efficiently and effectively by maintaining the science of entomology as an entity. It took 100 years to develop an organized and balanced approach to

insect control. The tendency to break up and relegate entomology to a position representing a phase of many sciences does not permit the coordinated approach necessary to solve the many diverse problems created by the thousands of insect species of economic significance to our nation.

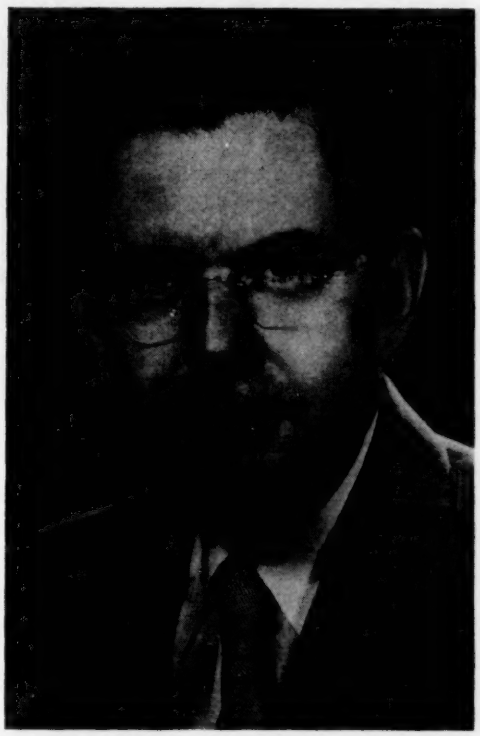
In the interest of efficiency we must strive to maintain an organizational structure that will permit maximum coordination of entomological activities. Only in this way will it be possible to plan and direct entomological activities on a broad base and in turn develop the necessary coordination of entomological activities with those in related fields of science.

E. F. KNIPLING, *Chief,*
*Entomology Research Branch,*
*Agricultural Research Service,*
*U. S. Department of Agriculture*

# OBITUARY

## Ralph Brownlee Swain

### 1912–1953



Ralph Brownlee Swain was born October 20, 1912 at Benton, Illinois. He was graduated from Soldan High School, St. Louis, Missouri in 1930; received his B.Sc. from Iowa State College in 1934, his M.Sc. from Colorado A. and M. College in 1936, and was awarded a Ph.D. by the University of Colorado in 1940. In 1938 and 1939 he worked as an agent for the Bureau of Entomology and Plant Quarantine on Mormon cricket control studies. He and SuZan Noguchi, artist and fellow student at the University of Colorado, were married December 24, 1938. Following receipt of his doctorate he was given an appointment with the Bureau at Gulfport, Mississippi, where he was in charge of studies on nematode parasites of the white-fringed beetle until 1945. After a short assignment as a civilian employee of the U. S. Air Corps, he reported for duty at the Bureau's Foreign Plant Quarantine Station in Hoboken, New Jersey. Here he remained until 1951, being assistant in charge at that time. In July 1951, he accepted a position as entomologist with the Office of Foreign Agricultural Relations and was assigned under the Point IV program to work in Nicaragua. His family accompanied him to Central America. Following a highly successful two years, Dr. Swain agreed to accept an additional year's assignment. Before entering on this he and his family returned to the States, purchased a new automobile and spent 3 months visiting relatives, friends, museums and laboratories. They were returning to Nicaragua via Pan-American highway when, on October 3, 1953, they were held up by bandits about 130 miles south of Mexico City. Not having the 2000 pesos demanded in cash, Dr. Swain offered travelers' checks, whereupon he was brutally shot.

Thus, at the hands of vicious outlaws, ended the too brief life of Ralph Swain, entomologist, naturalist, man of good will and devotee of service for others. This, in bare outline, is the story of his life. As an old friend the writer knows that much more could be said. Ralph and I first met during his freshman year at Iowa State. He came to college with an exceptional background in the biological sciences. He brought with him an extensive collection of Cicadellidae. He gave interesting accounts of natural history in the vicinity of St. Louis, Missouri, of his work during the summers between high school terms at the laboratory of his lifelong mentor, A. F. Satterthwait, and of his trip to the International Boy Scout Jamboree in England in 1929. The friendship begun then was broken only by his death.

His publications include papers on the Cicadellidae, on the biological control of insects, and on the Mormon cricket. He published a number of papers in Spanish while in Nicaragua. Of particular interest among his writings is "The Insect Guide," beautifully illustrated by Mrs. Swain. This book stands as a very useful and fitting memorial to their fruitful collaboration and to Ralph's work as an entomologist.

Friends in the United States and Nicaragua have contributed to a Memorial Fund and this is being used to build up a fine agricultural library at the escuela Nacional de Agricultura in Managua.

Dr. Swain was a member of the American Association of Economic Entomologists, Entomological Society of America, Kansas Entomological Society, the New York Entomological Society, John Burroughs Association and Sigma Xi.

Surviving relatives are his parents, Mr. and Mrs. Ralph Swain, two brothers, Robert and Jack, his wife, SuZan and two sons, Tomi Alfred and Ralph Adrian.

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